

Comparative Lead Isotope Dataset – Metadata Statement Supporting Documentation

This document is associated with the Comparative Lead Isotope Dataset and its file-level metadata statement. The controlled vocabularies and established wordlists used to control data entry for the dataset's "Period", "Tooth Type", "Fédération Dentaire Internationale (FDI) Tooth Notation", "Biological Sex Estimation", and "Age Category" columns are documented here. All future additions to the dataset should adhere to these data classifications. The full bibliographic references for the publications used to compile the lead isotope data and associated contextual information of the 307 samples, are also presented here.

Period

Supporting Documentation Table 1: The period a sample is associated with should be recorded in the dataset using the following vocabulary, which adheres to standardised terminology and dates established by Historic England (2023) and FISH (2023). Periods given in the literature should be transcribed into the dataset where appropriate, so as not to assign new meaning to the published data. *Locational qualifiers should be used before period names where necessary to denote where period date ranges differ considerably between countries (Heritage Data 2023; Young *et al.* 2023)

Period	Date Range
Palaeolithic	1,000,000 BC – 10,000 BC
Lower Palaeolithic	1,000,000 BC – 150,000 BC
Middle Palaeolithic	150,000 BC – 40,000 BC
Upper Palaeolithic	40,000 BC – 10,000 BC
Mesolithic	10,000 BC – 4,000 BC
Early Mesolithic	10,000 BC – 7,000 BC
Late Mesolithic	7,000 BC – 4,000 BC
Neolithic	4,000 BC – 2,200 BC
Early Neolithic	4,000 BC – 3,300 BC
Middle Neolithic	3,300 BC – 2,900 BC
Late Neolithic	2,900 BC – 2,200 BC
Bronze Age	2,600 BC – 700 BC
Early Bronze Age	2,600 BC – 1,600 BC
Middle Bronze Age	1,600 BC – 1,200 BC
Late Bronze Age	1,200 BC – 700 BC
Iron Age	800 BC – 43 AD
Early Iron Age	800 BC – 300 BC
Middle Iron Age	300 BC – 100 BC
Late Iron Age	100 BC – 43 AD
Scottish Iron Age*	700 BC – 400 AD
Irish Iron Age*	500 BC – 400 AD
Roman	43 AD – 410 AD
Early Medieval	410 AD – 1066 AD
Medieval	1066 – 1540 AD
Post-Medieval	1540 – 1901 AD

Tooth Type

Supporting Documentation Table 2: Tooth type is recorded in the dataset using both White and Folkens' (1991) and FDI (Leatherman 1972) notations. The former is more visually identifiable for the dataset user, whilst the latter does not use font formatting so prevents data loss during migration to plain text file format (e.g. .csv file).

Tooth	White and Folkens (1991)	Fédération Dentaire Internationale (FDI)
Permanent Dentition		
First incisor	I1 (I ¹ = upper; I ₁ = lower)	11/21/31/41
Second Incisor	I2 (I ² = upper; I ₂ = lower)	12/22/23/24
Canine	C1 (C ¹ = upper; C ₁ = lower)	13/23/33/43
First premolar	P1 (P ¹ = upper; P ₁ = lower)	14/24/34/44
Second premolar	P2 (P ² = upper; P ₂ = lower)	15/25/35/45
First molar	M1 (M ¹ = upper; M ₁ = lower)	16/26/36/46
Second molar	M2 (M ² = upper; M ₂ = lower)	17/27/37/47
Third molar	M3 (M ³ = upper; M ₃ = lower)	18/28/38/48
Right upper central incisor	RI ¹	11
Right lower central incisor	RI ₁	41
Left upper central incisor	LI ¹	21
Left lower central incisor	LI ₁	31
Right upper lateral incisor	RI ²	12
Right lower lateral incisor	RI ₂	42
Left upper lateral incisor	LI ²	22
Left lower lateral incisor	LI ₂	32
Right upper canine	RC ¹	13
Right lower canine	RC ₁	43
Left upper canine	LC ¹	23
Left lower canine	LC ₁	33
Right upper first premolar	RP ¹	14
Left upper first premolar	LP ¹	24
Right lower first premolar	RP ₁	44
Left lower first premolar	LP ₁	34
Right upper second premolar	RP ²	15
Left upper second premolar	LP ²	25
Right lower second premolar	RP ₂	45
Left lower second premolar	LP ₂	35
Right upper first molar	RM ¹	16
Left upper first molar	LM ¹	26
Right lower first molar	RM ₁	46
Left lower first molar	LM ₁	36
Right upper second molar	RM ²	17
Left upper second molar	LM ²	27
Right lower second molar	RM ₂	47
Left lower second molar	LM ₂	37
Right upper third molar	RM ³	18
Left upper third molar	LM ³	28
Right lower third molar	RM ₃	48
Left lower third molar	LM ₃	38

Deciduous Dentition		
Deciduous central incisor	di1 (di ¹ = upper; di ₁ = lower)	51/61/71/81
Deciduous lateral incisor	di2 (di ² = upper; di ₂ = lower)	52/62/72/82
Deciduous canine	dc1 (dc ¹ = upper; dc ₁ = lower)	53/63/73/83
Deciduous first molar	dm1 (dm ¹ = upper; dm ₁ = lower)	54/64/74/84
Deciduous second molar	dm2 (dm ² = upper; dm ₂ = lower)	55/65/75/85
Deciduous right upper central incisor	Rdi ¹	51
Deciduous right upper later incisor	Rdi ²	52
Deciduous right upper canine	Rdc ¹	53
Deciduous right upper first molar	Rdm ¹	54
Deciduous right upper second molar	Rdm ²	55
Deciduous left upper central incisor	Ldi ¹	61
Deciduous left upper later incisor	Ldi ²	62
Deciduous left upper canine	Ldc ¹	63
Deciduous left upper first molar	Ldm ¹	64
Deciduous left upper second molar	Ldm ²	65
Deciduous right lower central incisor	Rdi ₁	81
Deciduous right lower later incisor	Rdi ₂	82
Deciduous right lower canine	Rdc ₁	83
Deciduous right lower first molar	Rdm ₁	84
Deciduous right lower second molar	Rdm ₂	85
Deciduous left lower central incisor	Ldi ₁	71
Deciduous left lower later incisor	Ldi ₂	72
Deciduous left lower canine	Ldc ₁	73
Deciduous left lower first molar	Ldm ₁	74
Deciduous left lower second molar	Ldm ₂	75

Biological Sex Estimation

Supporting Documentation Table 3: The standardised vocabulary used to document biological sex estimation follows Buikstra and Ubelaker (1994). In the dataset, the full-word terminology (e.g. Male or Female) is preferred over the abbreviated notation for user clarity. Both formats are shown here to facilitate data entry, as many publications use the notation format. *The undetermined classification includes both individuals with an intermediate sex estimation and those whose sex could not be assessed.

Biological Sex Estimation	Common Notation
Male	M
Probable Male	M?
Probable Female	F?
Female	F
Undetermined*	U

Age-at-Death Estimation

Supporting Documentation Table 4: The age category of adult individuals should be recorded in the dataset using Buikstra and Ubelaker's (1994) standard terminology and established age ranges. For non-adults, the controlled vocabulary follows Scheuer and Black's (2000) age ranges. If an individual's estimated age range overlaps two categories, both should be expressed (e.g. Young Adult/Middle Adult).

Age Category		Age Range
Adults		
Young Adult		20 – 35 years
Middle Adult		35 – 50 years
Old Adult		50+ years
Non-Adults		
Neonate		Birth – 28 days
Infant		Birth – 1 year
Child		1 – 12 years
Adolescent		13 – 18 years
Juvenile		0-18 years

Resource References

Supporting Documentation Table 5: The full bibliographic references of the publications used to compile the lead isotope data and contextual information for the 307 human enamel samples are documented here. The site(s) discussed in each publication are listed to allow dataset users to look up references for relevant comparative data. Any publications linked to data added in the future should also be recorded in this table.

Publication Reference	Site(s) Discussed
Budd, P., Montgomery, J., Evans, J., Barreiro, B., 2000. Human Tooth Enamel as a Record of the Comparative Lead Exposure of Prehistoric and Modern People. <i>The Science of the Total Environment</i> , 263(1-3), pp. 1-10	Monkton-up-Wimbourne
Budd, P., Millard, A., Chenery, C., Lucy, S., Roberts, C., 2004a. Investigating Population Movement by Stable Isotope Analysis: A Report from Britain. <i>Antiquity</i> , 78(299), pp. 127-141	West Heslerton Mangotsfield Repton Monkton-up-Wimbourne Eagle Hotel Blackfriars
Budd, P., Montgomery, J., Evans, J., Trickett, M., 2004b. Human Lead Exposure in England from Approximately 5500 BP to the 16 th Century AD. <i>The Science of the Total Environment</i> , 318(1-3), pp. 45-58	Shepperton Monkton-up-Wimbourne West Heslerton Southwark Mangotsfield Winchester Stonehenge Bamburgh Repton Riccall Lihou Rivenhall

	Blackfriars
Evans, J., Chenery, C., Montgomery, J., 2012. A Summary of Strontium and Oxygen Isotope Variation in Archaeological Human Tooth Enamel Excavated from Britain. <i>Journal of Analytical Atomic Spectrometry</i> , 27(1), pp. 754-764	Aldro Bamburgh Callis Wold Chelsea Old Church Cladh Hallan Cnip St Mary's Cathedral Driffeld Terrace Eagle Hotel Galson Hereford Cathedral High Pasture Cave Kilpheder Mangotsfield Mine Howe Monkton-up-Wimbourne Mull Repton Riccall Stonehenge Towthorpe Wasperton West Heslerton
Jay, M., Richards, M.P., 2006. Diet in the Iron Age Cemetery Population at Wetwang Slack, East Yorkshire, UK: Carbon and Nitrogen Stable Isotope Evidence. <i>Journal of Archaeological Science</i> , 33(5), pp. 653-662	Wetwang
Melton, N., Montgomery, J., Knusel, C., Batt, C., Needham, S., Parker Pearson, M., Sheridan, A., Heron, C., Horsley, T., Schmidt, A., Evans, A., Carter, E., Edwards, H., Hargreaves, M., Janaway, R., Lynnerup, N., Northover, P., O'Connor, S., Ogden, A., Taylor, T., Wastling, V., Wilson, A., 2010. Gristhorpe Man: An Early Bronze Age Log-Coffin Burial Scientifically Defined. <i>Antiquity</i> , 84(1), pp. 796-815	Gristhorpe
Millard, A., Montgomery, J., Trickett, M., Beaumont, J., Evans, J., Chenery, S., 2014. "Childhood Lead Exposure in the British Isles During the Industrial Revolution" In Zuckerman, M.K. (Eds.) <i>Modern Environments and Human Health: Revisiting the Second Epidemiologic Transition</i> (First Edition). Hoboken: John Wiley and Sons, pp. 279-299	St Mary's Cathedral Chelsea Old Church Lukin Street Golden Lane
Montgomery, J., Evans, J., Powlesland, D., Roberts, C., 2005. Continuity or Colonisation in Anglo-Saxon England? Isotope Evidence for Mobility, Subsistence Practice, and	West Heslerton

Status at West Heslerton. <i>American Journal of Physical Anthropology</i> , 126(2), pp. 123-235	
Montgomery, J., 2006. Lead and Strontium Isotope Compositions of Human Dental Tissues as an Indicator of Ancient Exposure and Population Dynamics. PhD Thesis, Bradford: University of Bradford	Cnip West Heslerton
Montgomery, J., Evans, J., Chenery, C., 2009. "Strontium and Oxygen Isotope Analysis of Burials from Wasperton, Warwickshire" In Carver, M., Hills, C., Scheschkewitz, J. (Eds.) <i>Wasperton. A Roman, British and Anglo-Saxon Cemetery in Central England</i> . Specialist Report 4.2. Woodbridge: Boydell and Brewer	Wasperton
Montgomery, J., Evans, J., 2009. "Immigrants on the Isle of Lewis – Combining Traditional Funerary and Modern Isotope Evidence to Investigate Social Differentiation, Migration and Dietary Change in the Outer Hebrides of Scotland" In Gowland, R., Knusel, C. (Eds.) <i>The Social Archaeology of Funerary Remains</i> . Oxford: Oxbow Books, pp. 122-142	Cnip Galson
Montgomery, J., Evans, K., Chenery, S., Pashley, V., Killgrove, K., 2010. "Gleaming White and Deadly": Using Lead to Track Human Exposure and Geographic Origins in the Roman Period in Britain. <i>Journal of Roman Archaeology: Supplementary Series</i> , Suppl. 78(1), pp. 199-226	Gristhorpe Cnip Ratoath Rath Mine Howe High Pasture Galson Kilpheder Driffield Terrace Westness Graemsay Sumburgh Monkton-up-Wimbourne West Heslerton Callis Wold Towthorpe Aldro Cladh Hallan Ardachy Wetwang Eagle Hotel Mangotsfield Poundbury Wasperton Riccal Repton Blackfriars

	Hereford Cathedral Garton Slack Acklam Wold South Great Georges Street
Montgomery, J., Knusel, C., Tucker, K., 2011. "Identifying the Origins of Decapitated Male Skeletons from 3 Driffeld Terrace, York, Through Isotope Analysis" In Bonogofsky (Ed.) <i>The Bioarchaeology of the Human Head: Decapitation, Decoration, and Deformation</i> . Florida: University Press of Florida, pp. 141-178	3 Driffeld Terrace
Montgomery, J., Beaumont, J., Jay, M., Keefe, K., Gledhill, A.R., Cook, G.T., Dockrill, S.J., Melton, N.D., 2013. Strategic and Sporadic Marine Consumption at the Onset of the Neolithic: Increasing Temporal Resolution in the Isotope Evidence. <i>Antiquity</i> , 87(338), pp. 1060-1072	Sumburgh
Montgomery, J., Grimes, V., Buckberry, J., Evans, J., Richards, M., Barrett, J., 2014. Finding Vikings with Isotope Analysis: The View from Wet and Windy Islands. <i>Journal of the North Atlantic (Special Volume)</i> , 7(1), pp. 54-70	South Great Georges Street Westness Cnip Ricall Repton Rath Graemsay
Moore, J., Rose, A., Anderson, S., Evans, J., Nowell, G., Grocke, D.R., Pashley, V., Kirby, M., Montgomery, J., 2020. A Multi-Isotope (C, N, O, Sr, Pb) Study of Iron Age and Roman Period Skeletons from East Edinburgh, Scotland Exploring the Relationship Between Decapitation Burials and Geographical Origins. <i>Journal of Archaeological Science: Reports</i> , 29(1), 102075	Musselburgh
Muldner, G., Chenery, C., Eckardt, H., 2011. The 'Headless Romans': Multi-Isotope Investigations of an Unusual Burial Ground from Roman Britain. <i>Journal of Archaeological Science</i> , 38(2), pp. 280-290	3 Driffeld Terrace 6 Driffeld Terrace
Shaw, H., Montgomery, J., Redfern, R., Gowland, R., Evans, J., 2016. Identifying Migrants in Roman London Using Lead and Strontium Stable Isotopes. <i>Journal of Archaeological Science</i> , 66(1), pp. 57-68	Bishopsgate St Bartholomew's Hospital Cotts House Great Dover Street Hooper Street London Wall Mansell Street Spitalfields Market

	West Smithfield
Trickett, M.A., 2006. A Tale of Two Cities: Diet, Health and Migration in Post-Medieval Coventry and Chelsea Through Biographical Reconstruction, Osteoarchaeology and Isotope Biogeochemistry. PhD Thesis, Durham: University of Durham	Chelsea Old Church St Mary's Cathedral

Bibliography

Buikstra, J.E., Ubelaker, D.H., 1994. Standards for Data Collection from Human Remains. Fayetteville: Arkansas Archaeological Survey

Forum on Information Standards in Heritage, 2023. Chronology. [Online] Available at: <https://www.heritage-standards.org.uk/chronology/> [Access Dated: 19th December 2023]

Heritage Data, 2023. ScAPA: Scottish Archaeological Periods and Ages – Iron Age. [Online] Available at: <https://heritagedata.org/live/schemes/scapa/concepts/IA.html> [Access Dated: 19th December 2023]

Historic England, 2023. England's Historic Periods. [Online] Available at: <https://historicengland.org.uk/listing/the-list/historic-periods/> [Access Dated: 19th December 2023]

Leatherman, G., 1972. Fédération Dentaire Internationale. New Tooth Designation System. *Bulletins and Memoirs of the Society of Anthropology of Paris*, 9(1), pp. 83-85

Scheuer, L., Black, S., 2000. Developmental Juvenile Osteology. London: Academic Press

White, T.D., Folkens, P., 1991. Human Osteology. London: Academic Press

Young, J., Mac Uidhir, D., McDonagh, L., Kelly, A., Crowley, B., Finnegan, N., 2023. Heritage Ireland: Mesolithic – Iron Age (8000BC – 400AD). [Online] Available at: <https://heritageireland.ie/articles/mesolithic-iron-age-8000bc-400ad/> [Access Dated: 19th December 2023]

Supporting Document 1: Risk Assessment compiled for particle size analysis. Had this method been carried out in our own laboratories, this risk assessment would have been approved by the lab manager and signed off by every lab user undertaking this process.

Task/Activity Risk Assessment

Description of Task or Activity: <i>(to include enough information to establish the foreseeable hazards)</i>	Location(s): <i>(where will the activity or task take place?)</i>	Date:
Digestion of organic materials in soil/sediment samples prior to particle size analysis, using a 20% solution of 100Vol Hydrogen Peroxide. Flocculation is prevented by the addition of Sodium Hexametaphosphate	D112A and D132	7/12/22
Most significant risk(s):	Equipment required <i>(including PPE, tools, chemicals etc.)</i>	
Exposure to Hydrogen Peroxide Burns and electrocution	Equipment: • Disposable centrifuge tubes (50ml) • Centrifuge • Water bath • Aluminium foil • Glass beakers • Glass rods • Dropper pipettes • Distilled water • Balance Chemicals: • 20% solution of 100Vol Hydrogen Peroxide (H₂O₂) • Sodium Hexametaphosphate solution (Sodium Hexametaphosphate – NaPO₃ and Sodium Carbonate Na₂CO₃ dissolved in distilled water) PPE:	

				• Lab coats and eye protection to be worn in laboratory at all times • Safety gloves to be worn when handling Hydrogen Peroxide		
Work Step/ Tasks <i>(Describe the tasks/steps involved in the order of work)</i>	Hazards Identified for each task/step	Those at risk <i>(people who could be harmed)</i>	How could they be harmed? <i>(nature of injuries, damage that could result)</i>	Uncontrolled risk level <i>(level of risk without control)</i>	Required controls <i>(how the risk can be removed or reduced by for example engineered methods, safe systems of work, training and/ or personal protective equipment)</i>	Controlled risk level <i>(level of risk remaining when controls are in place)</i>
1) Weigh out approx. 0.5g of soil/sediment into 50ml centrifuge tube.	Soil handling/Bacteria in soil	Staff	Risk of contamination from bacteria/organic matter leading to infection and illness Risk of infection if soil makes contact with any cuts/wounds on skin. Risk of cross-contamination from handling to e.g. foods, drink, etc. Potential for respiratory irritation/aggravation of respiratory conditions if	4 x 3 Medium Risk	All required PPE to be worn in lab (lab coat and eye protection). Nitrile gloves can be worn if necessary/preferred. Prior assessment of soil samples by trained personnel to ensure contaminated samples are not sent to the lab. Thoroughly wash hands with soap and water after handling soils. If necessary/preferred, soil sample weighing can be performed under extraction in dust cabinet (D112A or D131).	2 x 2 Low Risk

			soil/sediment is fine and produces a "dust".			
2) Add approx. 20ml of 20% Hydrogen Peroxide to each tube (H ₂ O ₂ is added in excess and breaks down organic matter in sample). Undertaken within fume cabinet.	Exposure to Hydrogen Peroxide from chemical spillages/splashes	Staff	Hydrogen Peroxide can cause serious eye damage and eye/skin irritation, may be harmful if swallowed, and may have pressure build-up within storage bottles. Injuries from slips and trips. Cuts from glass breakages and risk of glass shards remaining in cuts. Risk of chemicals making contact with skin and both new/existing cuts from spillages/splashes.	4 x 4 High Risk (Known to occur, Major)	Staff to demonstrate and observe correct use of chemicals and transfer protocols. All lab users to wear safety glasses at all times. All lab users to wear disposable nitrile gloves at all times. All lab users to read COSHH form for Hydrogen Peroxide before handling. All work with Hydrogen Peroxide to be undertaken within fume cabinet.	2 x 3 Low Risk (Not likely, Moderate)
	Cuts from broken glass	Staff	Cuts from glass breakages and risk of glass shards remaining in cuts. Risk of chemicals		Broken glass to be removed by technical staff for appropriate disposal. Seek first aid immediately if cuts occur and tell first aider which	

			making contact with skin and both new/existing cuts from glass breakages.		chemicals have been handled.	
	Glove allergy	Staff	Allergic reaction to glove material when contact made with skin.	3 x 2 Low Risk (Could occur, Minor)	Wear appropriate gloves and inform colleagues/staff of any allergies.	2 x 2 Low Risk (Not likely, Minor)
3) Place rack of samples into boiling water bath to aid oxidation of matter (digestion).	Burns and electrocution from water bath	Staff	Burns from contact with hot water. Electrocution of user due to electrical malfunction or using equipment with wet hands. Possible fire hazard from overheating. Physical injury from manual handling and lifting equipment. Mechanical injury to hands and injuries from catching loose hair/clothing in equipment.	3 x 3 Medium Risk (Could occur, Moderate)	Work with care to prevent splashes. Do not handle/lift when filled with water. Ensure equipment is not faulty before use (in-date PAT testing). Do not operate with wet hands. Water bath should be safety checked as appropriate. Manual handling training carried out before lifting. Keep loose clothing/hair away from equipment, especially whilst circulation impeller and/or shaker mechanism in use (cover where appropriate).	2 x 2 Low Risk (Not likely, Minor)

					Ensure all equipment placed within water bath is safe to be heated to high temperatures.	
4) Monitor each tube for excessive reaction during digestion – carefully remove rack from heat if sample reacts violently, allow reaction to subside, then return to heat (a small amount of ethanol may be added to reduce frothing at this stage). This may need to be repeated several times until sample reacts steadily but not aggressively ('cold' digestion overnight prior to water bath heating may benefit some samples).	Burns and electrocution from water bath	Staff	Burns from contact with hot water. Electrocution of user due to electrical malfunction or using equipment with wet hands. Possible fire hazard from overheating. Physical injury from manual handling and lifting equipment. Mechanical injury to hands and injuries from catching loose hair/clothing in equipment.	3 x 3 Medium Risk (Could occur, Moderate)	Work with care to prevent splashes. Do not handle/lift when filled with water. Ensure equipment is not faulty before use (in-date PAT testing). Do not operate with wet hands. Water bath should be safety checked as appropriate. Manual handling training carried out before lifting. Keep loose clothing/hair away from equipment, especially whilst circulation impeller and/or shaker mechanism in use (cover where appropriate). Ensure all equipment placed within water bath is safe to be heated to high temperatures.	2 x 2 Low Risk (Not likely, Minor)

	Exposure to Hydrogen Peroxide from chemical spillages/splashes	Staff	Hydrogen Peroxide can cause serious eye damage and eye/skin irritation, may be harmful if swallowed, and may have pressure build-up within storage bottles. Injuries from slips and trips. Risk of chemicals making contact with skin and both new/existing cuts from spillages/splashes.	4 x 4 High Risk (Known to occur, Major)	Staff to demonstrate and observe correct use of chemicals and transfer protocols. All lab users to wear safety glasses at all times. All lab users to wear disposable nitrile gloves at all times. All lab users to read COSHH form for Hydrogen Peroxide before handling. All work with Hydrogen Peroxide to be undertaken within fume cabinet.	2 x 3 Low Risk (Not likely, Moderate)
	Exposure to ethanol from chemical spillages/splashes	Staff	Ethanol is highly flammable as both a liquid and vapour, can cause serious eye irritation, and may cause skin/respiratory irritation. Injuries from slips and trips. Risk of chemicals making contact with	4 x 4 High Risk (Known to occur, Major)	Staff to demonstrate and observe correct use of chemicals and transfer protocols. All lab users to wear safety glasses at all times. All lab users to wear disposable nitrile gloves at all times. All lab users to read COSHH form for Ethanol before handling.	2 x 3 Low Risk (Not likely, Moderate)

			skin and both new/existing cuts from spillages/splashes.			
5) Once sample reaction has stabilized, cover rack of samples with aluminium foil to avoid contamination and maintain oxidizing atmosphere, then return to water bath for 2 hours.	Burns and electrocution from water bath	Staff	Burns from contact with hot water. Electrocution of user due to electrical malfunction or using equipment with wet hands. Possible fire hazard from overheating. Physical injury from manual handling and lifting equipment. Mechanical injury to hands and injuries from catching loose hair/clothing in equipment.	3 x 3 Medium Risk (Could occur, Moderate)	Work with care to prevent splashes. Do not handle/lift when filled with water. Ensure equipment is not faulty before use (in-date PAT testing). Do not operate with wet hands. Water bath should be safety checked as appropriate. Manual handling training carried out before lifting. Keep loose clothing/hair away from equipment, especially whilst circulation impeller and/or shaker mechanism in use (cover where appropriate). Ensure all equipment placed within water bath is safe to be heated to high temperatures.	2 x 2 Low Risk (Not likely, Minor)
6) After 2 hours, check samples for complete digestion of	Burns and electrocution from water bath	Staff	See above.	3 x 3 Medium Risk	See above.	2 x 2 Low Risk (Not likely,

organic material (supernatant liquid appears transparent and is a green or yellowy/brown colour).				(Could occur, Moderate)		Minor)
7) If digestion is incomplete and organic matter is still present (supernatant liquid still cloudy or matter can be seen floating in liquid), centrifuge samples at 4000rpm for 4 minutes, decant supernatant liquid and repeat process from Step 2 until all organic matter is digested.	Burns and electrocution from water bath	Staff	See above.	3 x 3 Medium Risk (Could occur, Moderate)	See above.	2 x 2 Low Risk (Not likely, Minor)
	Exposure to Hydrogen Peroxide from chemical spillages/splashes	Staff	See Step 2.	4 x 4 High Risk (Known to occur, Major)	See Step 2.	2 x 3 Low Risk (Not likely, Moderate)
	Improper use of centrifuge leading to chemical exposure or equipment malfunction	Staff	If the centrifuge lid is not fitted properly, or if the centrifuge is not balanced/loaded correctly, reagents may spill. Improper loading of the centrifuge may cause explosion, potentially leading to chemical exposure and burns. Electrocution from	3 x 4 Medium Risk (Could occur, Major)	Ensure centrifuge is used on stable level surface. Ensure test tube lids are securely fastened prior to loading. Ensure all test tubes are balanced correctly and use blanks to balance if necessary. Long hair to be tied up. Centrifuge should be safety checked as appropriate and checked before use (PAT	2 x 2 Low Risk (Not likely, Minor)

			faulty equipment or contact between electrical equipment and liquid. Mechanical injuries such as entrapment within rotating parts of equipment. Possible injuries from chemical exposure due to splashed from improperly sealed vessels.		testing). Do not operate with wet hands.	
8) When all organic matter has been digested, centrifuge samples at 4000rpm for 4 minutes and decant supernatant liquid. Top up samples with distilled water, centrifuge and decant off supernatant liquid again.	Improper use of centrifuge leading to chemical exposure or equipment malfunction	Staff	See above.	3 x 4 Medium Risk (Could occur, Major)	See above.	2 x 2 Low Risk (Not likely, Minor)
	Cuts from broken glass (beakers)	Staff	Cuts from glass breakages and risk of glass shards remaining in cuts. Risk of chemicals making contact with skin and both new/existing cuts from glass breakages.	4 x 3 Medium Risk (Known to occur, Moderate)	Broken glass to be removed by technical staff for appropriate disposal. Seek first aid immediately if cuts occur and tell first aider which chemicals have been handled.	2 x 2 Low Risk (Not likely, Minor)

9) Add 20ml of distilled water to tube and then 2ml of Sodium Hexametaphosphate solution (wetting agent to aid deflocculation). Sample is now ready to be analysed on Coulter laser granulometer (Geography).	Exposure to Sodium Hexametaphosphate solution from chemical spillages/splashes	Staff	Sodium Hexametaphosphate can cause mild skin irritation at site of contact, irritation and redness to the eyes, throat irritation when ingested, as well as throat irritation and tightness in the chest with inhalation.	4 x 3 Medium Risk (Known to occur, Moderate)	Sodium Hexametaphosphate solution to be provided by Geography. Staff to demonstrate and observe correct use of chemicals and transfer protocols. All lab users to wear safety glasses at all times. All lab users to wear disposable nitrile gloves at all times. All lab users to read COSHH form for Sodium Hexametaphosphate before handling.	2 x 2 Low Risk (Not likely, Minor)
	Cuts from broken glass (beakers)	Staff	Cuts from glass breakages and risk of glass shards remaining in cuts. Risk of chemicals making contact with skin and both new/existing cuts from glass breakages.	4 x 3 Medium Risk (Known to occur, Moderate)	Broken glass to be removed by technical staff for appropriate disposal. Seek first aid immediately if cuts occur and tell first aider which chemicals have been handled.	2 x 2 Low Risk (Not likely, Minor)

Internal Guidance/Linked Documents:		MSDS and COSHH forms for Hydrogen Peroxide, Ethanol, and Sodium Hexametaphosphate solution.	
Competence Requirements:		Training provided to all users prior to sampling.	
Supervisor/Manager Review and Comment:			
Assessment Prepared by		Supervisor/Manager acceptance	
Name:	Aimee Parker	Name:	
Signature:	<i>AB Parker</i>	Signature:	
Date:	7/12/22	Date:	
This risk assessment should be read by those performing and supervising the work in conjunction with all relevant documentation including method statements and safe systems of work			

Health and Safety Risk Matrix

			Probability/ likelihood of risk realisation				
			Almost Impossible (1)	Not Likely to occur (2)	Could occur (3)	Known to occur (4)	Common occurrence (5)
			A freak combination of factors would be required for risk to be realised	A rare combination of factors would be required for risk to be realised	Could happen when additional factors are present otherwise unlikely to occur	Not certain to happen but an additional factor may result in risk being realised	Almost inevitable that risk will be realised
Potential Consequences	Severe (5)	One or more fatalities. Irreversible health problems	5	10	15	20	25
	Major (4)	Partial or medium-term, disabilities or major health problems	4	8	12	16	20
	Moderate (3)	Lost-time injuries or potential medium-term health problems	3	6	9	12	15
	Minor (2)	Minor, very short-term health concerns on recordable injury cases.	2	4	6	8	10
	Insignificant (1)	Inherently safe, unlikely to cause health problems or injuries	1	2	3	4	5

Extreme risk	High risk	Medium risk	Low risk

Supporting Document 2: The protocol for loss on ignition supplied by the Geography Department's technical team.

Department of Geography Laboratory Procedures

Preparation and analysis of samples for moisture content and loss on ignition

Prerequisites

Before carrying out the following procedure ensure you have completed the following paperwork/training.

1. Read through and understood the standard laboratory risk assessment for the determination of moisture content and loss on ignition.
2. Completed the safe laboratory working induction.
3. Have been instructed on the following procedure by a member of the lab staff.

If you run into any difficulties, are unsure what to do or have any accidents inform a member of the lab staff immediately.

Principle

The moisture content (MC) of a sediment sample is determined by drying a known mass of sediment at 105°C for 24 hours giving us our sample's dry mass. These values are required to calculate moisture content.

Loss on ignition (LOI) is a procedure used to determine the approximate percentage of organic carbon within a sediment/soil sample. The process involves igniting a known mass of sample for a specified duration of time and using the subsequent mass difference to calculate the result.

PPE requirements

The following PPE must be worn during this procedure:

- Lab coat
- Gloves
- Safety glasses
- Heat resistant gloves and tongs when handling hot crucibles

Equipment

- | | |
|-----------------------|---|
| • Porcelain crucibles | • Analytical balance (4 decimal places) |
| • Drying oven | • Muffle furnace |
| • Tongs | • Desiccator |

Method

1. MC and LOI require specialized crucibles capable of withstanding high temperatures. These are all marked with unique identifiers which have been burnt on using heat resistant markers. **Do not** add other markings to the crucibles. Dry your crucibles overnight in the drying oven at 105°C. Once cooled, place your crucibles in a desiccator to keep them dry. Remove your crucibles individually and record their mass to 4 decimal places. **This is your crucible mass (A).**
2. Add 3-5 g of sample to each pre-weighed crucible and record the mass to 4 decimal places. Work as efficiently as possible as you want to minimize the amount of time your crucibles and samples are open to the atmosphere. **This step provides you with your crucible plus wet sample mass (B).**
3. Dry your crucibles and samples in a drying oven at 105°C for 24 hours. Place in a desiccator to cool prior to weighing. Once cool, record each crucible's mass to 4 decimal places, removing them from the desiccator one at a time. **This is your crucible plus oven dry sediment mass (C).**
4. Place your crucibles and samples into a **cold** muffle furnace and heat your samples to 550°C for 4 hours. It is essential that samples are placed into the furnace whilst it is cold as a sudden temperature shock can cause samples to ignite, spitting material which will contaminate other samples and invalidate your results. It is also far safer to place items into a cold furnace.
5. After 4 hours turn the furnace off and very carefully remove your samples from the furnace using long-reach tongs. Place the samples carefully inside a glass desiccator and allow to cool.
6. Once your samples have cooled sufficiently (usually after around 45 minutes) record the mass of the crucibles one by one to 4 decimal places. Please take care when opening the desiccator for the first time after cooling as negative pressure will have developed inside the desiccator. To avoid a sudden in-rush of air, the desiccator should be opened slowly. **This step provides you with your crucible plus ash sediment mass (D).**
7. To calculate your results, use the values you have obtained above in the following calculations.

$$MC \% = \left(\frac{\text{wet sample mass} - \text{dry sample mass}}{\text{wet sample mass}} \right) \times \frac{100}{1}$$

$$LOI \% = \left(\frac{\text{dry sample mass} - \text{ash sample mass}}{\text{dry sample mass}} \right) \times \frac{100}{1}$$

Where:

- wet sample mass = B – A
- dry sample mass = C – A
- ash sample mass = D – A

Supporting Document 3: The protocol for particle size analysis sample preparation supplied by the Geography Department's technical team.

Preparation of Samples for Laser Diffraction Particle Size Analyser

Prerequisites

Before carrying out the following procedure ensure you have completed the following:

4. Read and understood the "Preparation of Samples for Laser Diffraction Particle Size Analyser" risk assessment.
5. Read and understood the COSHH form for hydrogen peroxide (H₂O₂) and sodium hexametaphosphate solution.
6. Have been instructed on the following procedure by a member of the lab staff.

PPE requirements

Laboratory coat, nitrile gloves, safety glasses

Chemicals

Hydrogen peroxide (20%)

Strong oxidizing agent and cause explosive reactions with several chemicals. Is an irritant and skin contact can cause burns.

Sodium hexametaphosphate solution 3% w/v (containing sodium carbonate)

Causes eye irritation

Consumables

- 50 ml centrifuge tubes (1 per sample)
- Foil
- Plastic pipettes

Equipment

- Fume cupboard
- Water bath and cover
- Centrifuge
- Balance
- Sediment sampling tools eg. spatula
- Permanent marker pen
- Wash bottle of deionized water
- Glass beaker
- Centrifuge tube rack
- Glass rods

Method

1. Weigh out the sediment sample into a 50 ml centrifuge tube and place tubes into a rack (dry sediment samples must be passed through a 2 mm sieve first). Make sure the weight of the sample is recorded. Do not place lids on the tubes.

The amount of sediment required will depend on the grain size and how organic the material is. Typically, ~ 0.5g of sediment is processed (if mainly clay/silt only ~0.2g; if mainly coarse sand between 1-3g; if high in organic material roughly estimate the percentage of organic material and adjust the weight accordingly to leave approximately 0.5g of sample after peroxide digestion).

2. Move the rack of samples into a fume cupboard. Add approximately 20ml of 20% hydrogen peroxide solution (20 vol) to each of the samples. **Do not** place lids on the tubes (gas is evolved as part of the oxidation reaction and would cause a capped tube to burst). The hydrogen peroxide is added in excess and breaks down the organic matter in the sample; generally, only mineral matter is considered for particle size analyses.
 3. If the hydrogen peroxide does not react violently with the sediment, the rack of centrifuge tubes can be covered with aluminium foil and placed into the water bath (set to 80°C). Covering the samples with foil not only prevents any cross contamination due to vigorous reaction but also helps to maintain an oxidising atmosphere above each sample, aiding the reaction. The foil must be labelled with the owner's name and date. If the samples react vigorously, leave them overnight in the fume cupboard, placing them in the water bath when the reaction has reduced/stopped. A small amount of ethanol may be added to reduce frothing at this stage.
 4. Heat samples for 2 hours in the water bath until all the organic material has been digested by the hydrogen peroxide. Ensure the water bath does not dry out, the water bath cover will reduce the chance of this happening.
 5. Carefully remove the sample rack from the water bath and check your samples in the fume cupboard. If all organic matter has been digested, then the supernatant liquid will be transparent and a green or yellowy/brown colour. If any organic matter is still present (the liquid is still cloudy or matter can be seen floating in the liquid) centrifuge the samples at 5 minutes at 3300 rpm (if using the Rotanta 460 centrifuge) decant the supernatant liquid and repeat the process from Step 2 until all organic matter is digested.
 6. When all organic matter has been digested, centrifuge the samples at 3300 rpm for 5 minutes (Rotanta 460 centrifuge) and decant the supernatant liquid. Top up the samples with distilled water, centrifuge and decant off the supernatant liquid again.
 7. Add 20ml of distilled water to the tube and then 2ml of sodium hexametaphosphate solution. Sodium hexametaphosphate solution is a wetting agent and aids deflocculation. Stir with a glass rod.
 8. Leave the sample overnight. The sample is now ready to be analysed on the laser diffraction particle size analyser.
-

Reagent information

Hydrogen Peroxide (20% v/v)

The hydrogen peroxide is prepared in 2 litre quantities by measuring out 400 ml of 100 volumes hydrogen peroxide (bought in concentration) into a pre-labelled reagent bottle and adding 1600ml of deionized water to make up to the 2-litre mark.

Sodium Hexametaphosphate solution (3.3%w/v)

To prepare the sodium Hexametaphosphate solution weigh out 33g of Sodium Hexametaphosphate ($\text{Na}_6\text{P}_6\text{O}_{18}$) and 7g Sodium Carbonate (Na_2CO_3) and dissolve in approximately 500 ml distilled water in a 1 litre volumetric flask, when dissolved make up to the mark with deionised water.

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Isotope Specialist Report: Multi isotope analysis of three humans and four animals from Großmugl, Austria.

Summary

This report presents the results of an isotopic study into the diet and mobility of three individuals from the Hallstatt period site of Großmugl, Austria. Carbon isotope results indicate that these three individuals ate a predominantly terrestrial C₃ diet consistent with Austria and other regions of Western and Central Europe during the Hallstatt period. The nitrogen isotope ratios observed in the individuals are unusually high in comparison to contemporaneous populations, and may suggest the use of crop manuring, consumption of omnivorous animals (e.g., suckling pigs), and/or the inclusion of freshwater fish in their diet. Periods of nutritional or physiological stress have also been identified in each individuals' incremental dentine profile. The strontium and oxygen isotope data from the Großmugl individuals and the associated faunal remains are consistent with the site and the surrounding area, although these values are not unique and can be found across many other areas of Europe such as Germany.

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Note: The isotope background sections of this report are based on a template adjusted to suit the specifics of this particular project. Much of the wording is therefore reproduced for other projects. These sections are therefore suitable for unpublished and general reporting but may require omission or adjustment for full publication

1. Introduction

This report presents the results of the multi-isotope analysis of three individuals recovered from the Hallstatt period site of Großmugl, Austria. Teeth and rib fragments were analysed for carbon, nitrogen, strontium, and oxygen isotopes to reconstruct diet and childhood mobility. Complete permanent second molars (M2) representing life between 2.5 years and 15.5 years were analysed for SK1 and SK3 and a permanent lower incisor (I) with incomplete root apex formation was analysed from SK2 representing life between 7.5 months and approximately 8.5 years. Dentine from permanent second molars of three sheep (*Ovis aries*) and a permanent third molar of a pig (*Sus scrofa*) found at Großmugl were analysed for strontium isotopes. The results have been interpreted and discussed in context with previously published data from contemporaneous sites.

2. Dietary Reconstruction

2.1. Carbon and nitrogen isotope analysis

Isotopic analysis of carbon ($\delta^{13}\text{C}$) and nitrogen ($\delta^{15}\text{N}$) is a well-established technique for the reconstruction of diets in past populations using archaeological teeth and bones. Within these two tissue types, collagen is the predominant protein present and provides a rich source of averaged $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values. The composition of these $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values reflect the isotopic composition of the foods consumed during the tissue's formation. This is due to the metabolism and reuse of dietary proteins acquired from the plant and animal products consumed during collagen synthesis. Therefore, once metabolic fractionation has been accounted for, these $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values can be used to garner insights into not only the types and quantities of food resources utilised by a population, but also the socioeconomic and cultural influences surrounding the dietary practices of groups as well as individuals.

The variations that arise in $\delta^{13}\text{C}$ values result from differences in ecosystems (marine vs. terrestrial) and the photosynthetic pathways (C_3 and C_4) used by plants in their

manufacture of carbohydrates. As such, variations in $\delta^{13}\text{C}$ values allows differentiation between the relative contribution of C_3 or C_4 plants and the animal products based on these plants, to diet. C_4 plants tend to grow in warmer or more arid climates, where their photosynthetic pathway allows them to cope with less water availability.

Variability in $\delta^{15}\text{N}$ isotope values reflects the balance between biological nitrogen fixation, biosphere recycling and nitrogen release. This variability facilitates the visualisation of terrestrial and marine food source input into diet as marine based food sources tend to be more enriched in ^{15}N than land-based food sources. In addition to this, $\delta^{15}\text{N}$ values also vary with trophic level due to metabolic fractionation, creating a 2–6 ‰ enrichment with every trophic level shift. This shift is most noticeable in marine food consumers as aquatic food sources have high $\delta^{15}\text{N}$ values owing to the relatively long food chains compared to those observed in terrestrial food sources. Combining the analyses of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values can facilitate the interpretation of plant, animal and marine protein contributions to past diets. This allows distinctions to be made between broad categories of food groups, such as herbivore vs. carnivore or marine vs. terrestrial input and any potentially non-local influence on diet.

2.2. Materials and methods

Bone and dentine samples were collected from the three individuals and cleaned and abraded to a depth of $>100\text{ }\mu\text{m}$ using a tungsten carbide dental drill. Dentine increments were prepared and sampled following method 2 in Beaumont *et al.* (2013). Collagen extraction was carried out using O'Connell and Hedges (1999) method, briefly summarised here: bone and dentine samples (c. 200 mg) were demineralised in refrigerated 0.5M HCl for several weeks and then thoroughly washed in Millipore Alpha Q (MQ) water before gelatinisation in a pH 3 solution of HCl at 70°C for 48 hours. The samples were then filtered, frozen and freeze-dried before being weighed into tin capsules and measured in duplicate using a Thermo Scientific Delta V Advantage isotope ratio mass spectrometer in the Stable Isotope Biogeochemistry Laboratory (SIBL), Durham University. Calibration using internal reference samples (e.g., Glutamic Acid, Glycine, SPAR and Urea) and international reference standards (e.g., USGS 24, USGS 40, IAEA 600, IAEA N1, IAEA N2) determined a standard

deviation of $\pm 0.1\text{‰}$ (1σ) for collagen carbon and nitrogen isotopes. Replicate analysis of collagen samples averaged a standard deviation of $\pm 0.2\text{‰}$ (1 sd).

2.3. Results and interpretation

The mean $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ data from the rib and dentine samples are presented in Table 1 and Figure 1. Due to the fast rate of bone turnover in the ribs, the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values measured in these tissues reflect an average for the dietary protein consumed during approximately the last 5 years prior to death (Cox and Sealy 1997; Fahy *et al.* 2017). The $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ data from the permanent second molars of SK1 and SK3 represent the dietary protein consumed between the ages of 2.5 years (± 0.5 years) to 15.5 years (± 0.5 years), while the data from the permanent incisor of SK2 represents dietary protein consumption between the ages of 7.5 months (± 1.5 months) to 8.5 years (± 0.5 years). For SK1 and SK3, the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ data from the incremental dentine samples represent childhood diet and can be compared to the rib samples, which reflect diet later in life during adolescence/adulthood, to identify any potential dietary changes. As SK2 likely died in later childhood, the development of the rib and the incisor would have overlapped, meaning that these two tissues can be used together to infer dietary behaviour across this individual's short lifetime.

The mean $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values from the Großmugl individuals are presented in Figure 1 along with the same data from contemporaneous Hallstatt burials found at nine different sites in Northern Austria (Le Huray and Schutowski 2005). The $\delta^{13}\text{C}$ values from the rib samples of SK1 and SK3 align with those expected for individuals consuming a diet consisting wholly or predominantly of terrestrial C_3 cereals (e.g., wheat, rye, and barley), fruit and vegetables and animals fed on these plants. These $\delta^{13}\text{C}$ values do not suggest the inclusion of C_4 plants or marine resources within the diet (Kellner and Schoeninger 2007). SK2 has a slightly higher $\delta^{13}\text{C}$ value, which is greater than the upper boundary expected for a purely C_3 terrestrial diet in studies of northwest European populations (Bonsall *et al.* 2009) but this boundary may be slightly higher in lower latitudes of mainland Europe due to climatic differences producing higher $\delta^{13}\text{C}$ values in plants (van Klinken *et al.* 1994), which may suggest a 100% terrestrial diet for SK2 is a strong possibility.

The $\delta^{15}\text{N}$ values observed in the rib samples from SK1 and SK3 are consistent with consumption of a predominantly mixed plant and animal protein diet, including such herbivorous mammals as sheep (*Ovis aries*) or cattle (*Bos taurus*). Both individuals' $\delta^{15}\text{N}$ values are slightly higher than the ~3-5‰ increase expected for a single trophic level shift (Bocherens and Drucker 2003) when compared to published mean $\delta^{15}\text{N}$ values for terrestrial herbivorous faunal data from the contemporaneous Hallstatt settlement of Altdorf, Bavaria (5.4‰ in Murray and Schoeninger 1988; Wells 1986). This may imply that SK1 and SK3 sourced some of their dietary protein from terrestrial omnivores, such as pigs (*Sus scrofa*), as well as herbivores during later adolescence/adulthood. As both sheep and pig remains have been found at Großmugl, it is possible that throughout their lives, SK1 and SK3 consumed a diet with protein derived from both herbivorous and omnivorous mammals and their products, as well as from plants.

The $\delta^{15}\text{N}$ value measured in the rib collagen of SK2 is much higher than the other two individuals and is unusually high for prehistoric farming populations in Europe. It is not typical for an individual exclusively sourcing their protein from terrestrial herbivores (Schoeninger and DeNiro 1984). The consumption of a significant amount of freshwater fish could explain this high $\delta^{15}\text{N}$ value, with aquatic food webs being typically more complex than terrestrial ones and having more trophic levels which each have a ^{15}N -enrichment between them. Freshwater fish, therefore, often have higher $\delta^{15}\text{N}$ values than terrestrial mammals, which are in turn incorporated into and reflected in human tissue upon consumption (Minigawa and Wada 1984; Schoeninger and DeNiro 1984; Dufour *et al.* 1999). Consumption of omnivorous and/or young suckling pigs is another potential explanation, as these animals would have higher $\delta^{15}\text{N}$ values than expected due to them either being fed animal protein such as dairy or meat as a form of animal husbandry, or still consuming their mothers' milk at the time they are culled (Jay and Richards 2006). Remains of piglets found within Iron Age sites and burials in Britain have previously been used to suggest that these young animals were an important component within the diet (Jay and Richards 2006). The corresponding $\delta^{13}\text{C}$ value would normally be considered too low for these elevated $\delta^{15}\text{N}$ values to be caused by marine resource contributions in the diet.

Alternatively, considering the estimated young age at death for SK2, this significantly higher $\delta^{15}\text{N}$ value observed in the rib collagen may be due to nutritional or

physiological stress experienced in the few years prior to death, rather than dietary behaviour. High $\delta^{15}\text{N}$ values have previously been linked to periods of stress caused by numerous diverse factors including illness, malnutrition, starvation, puberty, fasting, and metabolic disorders; whereby the body's tissues become enriched in ^{15}N due to the breakdown of stored protein to provide enough energy to supplement dietary protein intake (Beaumont and Montgomery 2016; Hatch *et al.* 2016; Mekota *et al.* 2006; Fuller *et al.* 2005). This stress may also manifest as skeletal abnormalities, although no remains were available to assess this. SK2's mean dentine $\delta^{15}\text{N}$ value (13.7‰) is also unusually high and the incremental profile (discussed below) supports the data from the rib in suggesting that this individual likely experienced significant stress throughout their life. The $\delta^{15}\text{N}$ data for SK2 ultimately suggests that although this individual's protein intake may have been supplemented by additional resources such as freshwater fish or omnivorous/suckling pigs alongside the expected terrestrial herbivores and plants, the noticeably high $\delta^{15}\text{N}$ values are more likely linked to periods of stress occurring before and leading up to this individual's death in childhood.

The $\delta^{15}\text{N}$ values from the Großmugl individuals are significantly higher than the contemporaneous Hallstatt burials from across Northern Austria (Figure 1), which range from 7.1‰ to 10.1‰ (LeHuray and Schutkowski 2005). This may result from the use of farming practices at Großmugl such as crop manuring, which can elevate $\delta^{15}\text{N}$ values by several per mille (Bogaard *et al.* 2007; Fraser *et al.* 2011). The data in Figure 1 also implies that the Hallstatt period in Austria, and possibly more broadly across Central Europe, was characterised by a largely terrestrial but still varied diet. Whilst the Großmugl individuals and the animals they ate were likely C_3 plant consumers, the individuals in Figure 1, and Stadlau in particular, appear to have been consuming a mixed C_3/C_4 diet, either from ingestion of C_4 plants (e.g., millet or sorghum) or the consumption of C_4 -plant-fed animals (LeHuray and Schutkowski 2005). A mixed C_3/C_4 also appears to be the norm for Austria in the later early medieval period (Figure A1).

[REDACTED] Table 1: Mean $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ data from incremental dentine and bulk rib collagen of the Großmugl individuals

Skeleton	Dentine* (mean)		Rib	
	$\delta^{13}\text{C}_{\text{VPDB}} \text{ ‰}$	$\delta^{15}\text{N}_{\text{AIR}} \text{ ‰}$	$\delta^{13}\text{C}_{\text{VPDB}} \text{ ‰}$	$\delta^{15}\text{N}_{\text{AIR}} \text{ ‰}$
SK1				
SK2				
SK3				

* The full dataset for the incremental analysis is included in the Appendix (Table A1-A3)

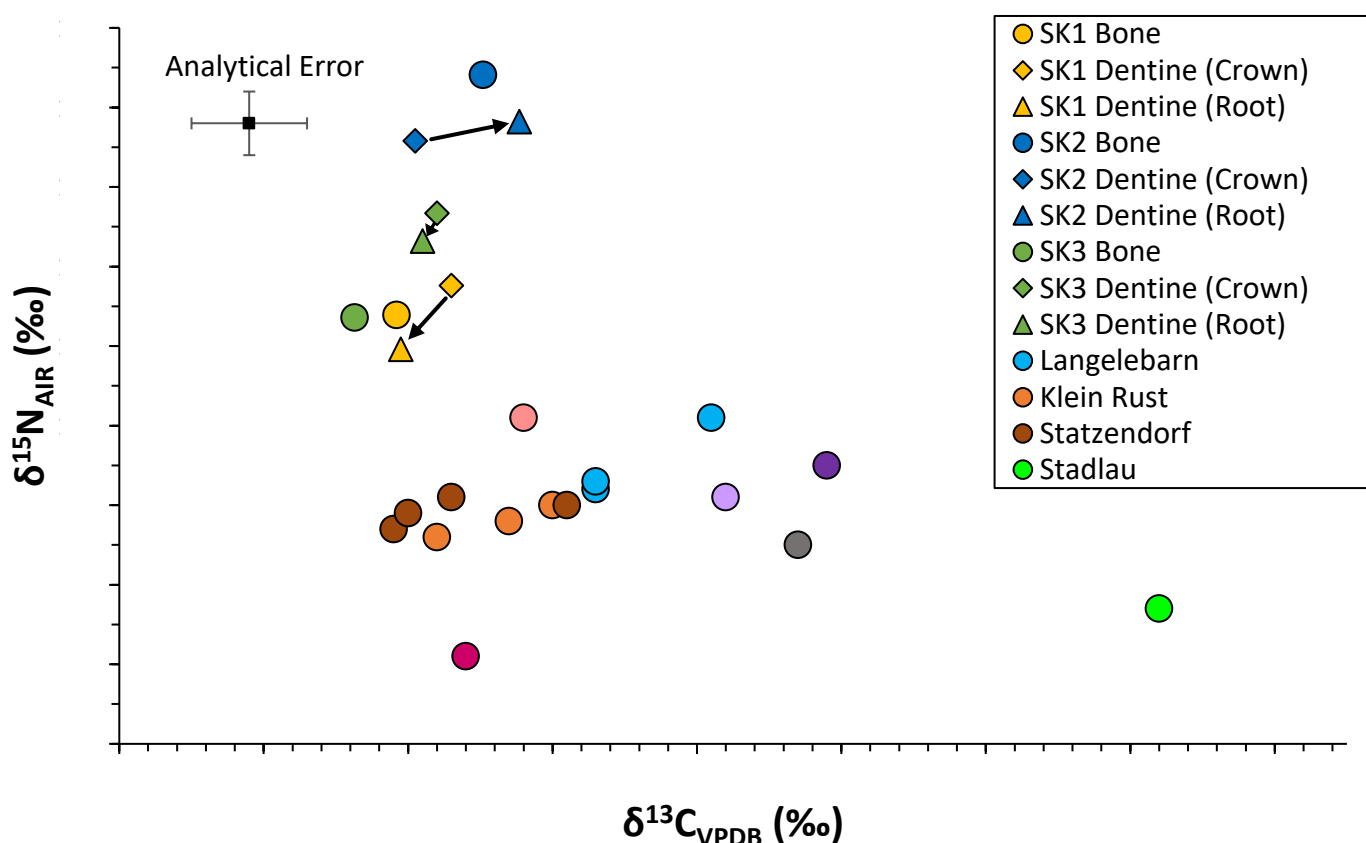


Figure 1: Großmugl $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ data shown alongside published comparative data from contemporaneous Hallstatt Culture humans from Northern Austria (Le Huray and Schutkowski 2005). The Großmugl dentine values are separated into crown and root and are paired by an arrow from the crown to the later-forming root. Analytical error is shown at 2σ .

Whilst the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values from bone and dentine collagen predominantly reflect the protein component of the diet, the $\delta^{13}\text{C}$ values from bone and enamel apatite represent the whole diet (carbohydrates, proteins, and fats) (Ambrose and Norr 1993; Jim *et al.* 2004 Froehle *et al.* 2010). By comparing the $\delta^{13}\text{C}$ values from collagen and apatite, a more comprehensive assessment of past diets can be made (Kellner and Schoeninger 2007). The $\delta^{13}\text{C}$ values from the enamel apatite of the Großmugl individuals are presented in Table 2 (see section 3.1 below) and are plotted against the $\delta^{13}\text{C}$ values from the individuals' crown dentine collagen in Figure 2 alongside the dietary regression lines adapted from Froehle *et al.* (2010). As both of these tissues form during the same period of life, the $\delta^{13}\text{C}$ values reflect the composition of the individuals' whole diet during the development of the crown of their sampled tooth throughout childhood. For the second permanent molars from SK1 and SK3, the $\delta^{13}\text{C}$ values represent whole diet between the ages of 2.5 years (± 0.5 years) and 8.5 years (± 0.5 years). Whereas, for the permanent incisor from SK2, the $\delta^{13}\text{C}$ values represent whole diet between the ages of 7.5 months (± 1.5 months) and 4.5 years (± 0.5 years) (AlQahtani 2009; Beaumont and Montgomery 2015). The regression lines in Figure 2 distinguish between C_3 and C_4 /marine diets. The left of these lines reflect consumption of entirely C_3 resources, and individuals move along the line towards the right of the plot with increasing amounts of C_4 or marine protein incorporated into their diet. As shown in Figure 2, the $\delta^{13}\text{C}$ values measured in the crown dentine collagen and the enamel apatite of the Großmugl individuals cluster tightly on the lower left of the plot, implying a predominantly terrestrial C_3 diet was consumed by all individuals during childhood with no or minimal contributions from C_4 and marine food sources. This dietary behaviour is also corroborated by the rib $\delta^{13}\text{C}$ values, implying that SK1 and SK3 continued to rely on C_3 plants and C_3 -plant fed animals in their later life, and SK2's diet likely did not change radically in the years leading up to death.

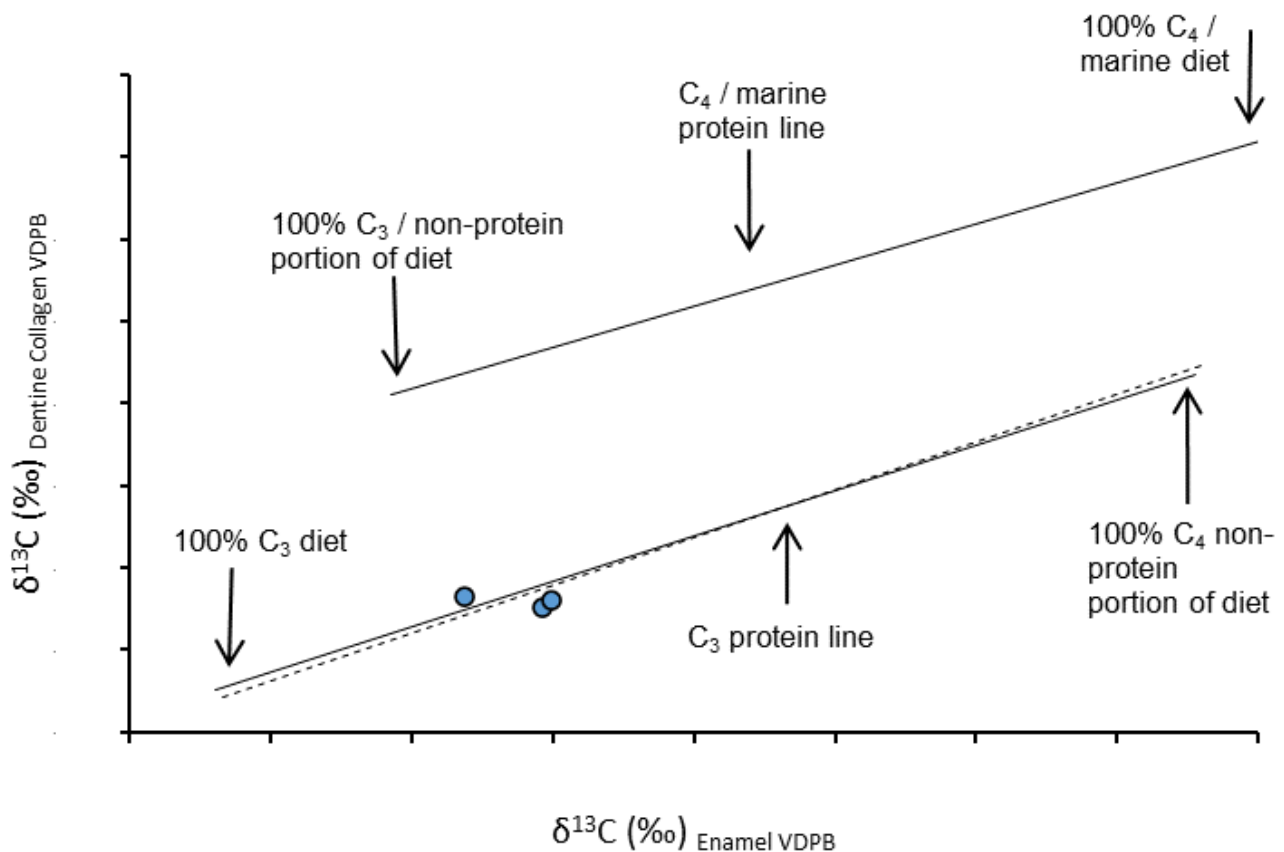


Figure 2: Crown dentine collagen and tooth enamel apatite $\delta^{13}\text{C}$ values from the Großmugl individuals. (Regression lines from Froehle *et al.* 2010, adapted by Jay, M.)

Incremental dentine profiles for the Großmugl individuals are presented in Figure 3, with the full incremental datasets available in the appendix (Tables A1 to A3). The incremental profiles for SK1 and SK3 represent the full developmental period of the permanent second molar, whilst the profile for SK2 covers the period between the start of the incisor's development up to the individual's death, at which point the root apex was not fully formed. All ages are approximate. All of the dentine increments produced C:N atomic ratios within the acceptable range for well-preserved collagen (DeNiro 1985; Ambrose 1990; van Klinken 1999), except for increments 9 and 10 from SK2's incisor (see Table A2). The C:N atomic ratios of these two increments are only just outside of DeNiro's (1985) accepted range of 3.1 – 3.5, so are still included within the incremental dentine profile discussed below. Due to the already small number of increments the incisor yielded, these two increments from the root are important to help infer the diet of SK2 up to the point of death when root development was arrested.

SK2's profile shows a gradual rise in $\delta^{13}\text{C}$ from the start of the incisor's development until around 5.5 years, which may indicate the consumption of small amounts of C_4 plants or marine protein during early childhood. The $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values from the SK2's dentine increments are relatively consistent with the values seen in the rib, for which the developmental period would have overlapped with that of the incisor. SK2's $\delta^{15}\text{N}$ values remain high throughout the individual's life, from the start of the incisor's development until the child's death at a young age and are significantly higher than those seen in the incremental profiles of SK1 and SK3. These consistently high values are either indicative of eating high-trophic level foods (such as breastmilk or omnivores) throughout childhood or they may support the inference that SK2 suffered through several periods of stress, with their body potentially being under such continuous prolonged stress from such a young age that the nitrogen isotope composition of their tissues never had a chance to return to normal dietary levels before death. Instead, the dentine $\delta^{15}\text{N}$ values which would usually primarily reflect the individual's protein consumption may have been considerably impacted by the ^{15}N -enrichment of tissues as a result of the body frequently being in a catabolic state due to the nutritional, physiological, and/or pathological stress it was under (Mora 2022; Beaumont and Montgomery 2016; Hatch *et al.* 2006; Mekota *et al.* 2006; Fuller *et al.* 2005). If these $\delta^{15}\text{N}$ values are indicative of diet rather than stress, the relatively consistent $\delta^{15}\text{N}$ profile could indicate a stable protein diet, with previous suggestions of the inclusion of omnivorous/suckling pig or marine protein within SK2's diet or the use of crop manuring potentially explaining the significantly high values.

SK3 has a relatively flat $\delta^{15}\text{N}$ profile from the age of 4.5 years onwards and shows minor variation in $\delta^{13}\text{C}$ values between 4.5 – 11.5 years, indicating a relatively stable terrestrial C_3 diet during childhood with minimal input from other food sources. There is a slight increase in $\delta^{13}\text{C}$ values between 11.5 and 13.5 years which may indicate very minor contributions from C_4 plants or marine protein to the diet over a limited time period, followed by a return to a predominantly C_3 terrestrial diet. The rib $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values are slightly lower than those measured in the dentine, suggesting that during adulthood this individual may have consumed less animal protein, although the difference between the values measured in the two tissues does not constitute a significant shift in dietary behaviour. The incremental profile of SK1 shows more variation. Between the ages of 5 – 8.5 years, the lower $\delta^{15}\text{N}$ values suggest this

individual consumed less animal protein, potentially due to limited availability of animal produce or a greater reliance on plant-based foods. A concurrent increase in $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values then occurs between 12 and 14 years, which may indicate the reintroduction of greater amounts of animal protein to the diet or an increased consumption of terrestrial omnivores or marine fish. The $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values decrease after 14 years until the end of the incremental profile and become consistent with the rib values, implying that this individual maintained a predominantly terrestrial C_3 diet into adulthood.

The second permanent molars of SK1 and SK2 both show a co-occurring decrease in $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ from the beginning of development until 4.5 – 5 years. This pattern is usually typical of weaning, but it is not expected to be visible in the second permanent molar at such a late age, suggesting that this decrease in $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ could more likely be due to a dietary shift occurring for both of these individuals around the same age (Jay 2009; Chinique de Armas *et al.* 2022). The decreasing $\delta^{15}\text{N}$ values during this period indicate less animal protein, or lower-trophic level animal protein, was being consumed and are consistent with a trophic level shift down the food chain, which is especially evident in SK1's profile. This change in diet during early childhood may therefore represent a gradual transition away from consuming significant quantities of animal produce such as dairy products and milk (as perhaps seen in the profile of SK2). Perhaps this was a movement towards a more typical terrestrial "adult" diet, as suggested by the lower and more stable $\delta^{13}\text{C}$ values after this age which are more similar to those observed in the rib collagen. There are many social, cultural, economic, and/or environmental reasons why a dietary change may occur at a young age, and it is particularly interesting that SK1 and SK3 appear to experience it around the same age. These two individuals also seem to have experienced a period of stress around the same age, with an increase in $\delta^{15}\text{N}$ values and co-occurring decrease in $\delta^{13}\text{C}$ values visible in both incremental profiles. This opposing covariance occurs between the ages of 8.5 – 12 years for SK1 and 9.5 – 11.5 years for SK3 and is a potential indicator of physiological or nutritional stress affecting the body (Beaumont and Montgomery 2016).

Mean $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of the crown and root increments of each tooth have also been plotted separately in Figure 1 alongside the data for the rib collagen and the comparative northern Austrian Hallstatt culture burials (Le Huray and Schutkowski

2005). For the second permanent molars of SK1 and SK3, crown development is represented by the first four dentine increments, and for SK2's incisor only the first three increments represent crown development. The separate plotting of these two stages of tooth development highlights that the mean crown $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of SK1 and SK3 are higher than those of the later-forming root, whilst the opposite is observed for SK2. This inverse trend emphasises the unusually high $\delta^{15}\text{N}$ values seen towards the end of SK2's profile and supports the inference that this individual suffered significant stress before their death, in contrast to SK1 and SK3 who survived into late adolescence/adulthood and experienced minor periods of stress and/or dietary changes before settling into a stable terrestrial C_3 diet.

In sum, taken together, the carbon and nitrogen isotope ratios from the Großmugl individuals are consistent with a predominantly terrestrial C_3 diet but appear to be quite different (lower $\delta^{13}\text{C}$ and/or higher $\delta^{15}\text{N}$) from both Iron Age and Early Medieval populations from Austria. This may imply the use of crop manuring, consumption of freshwater fish and/or the inclusion of higher trophic level foods such as omnivorous animals (e.g., suckling pigs) within the diet.

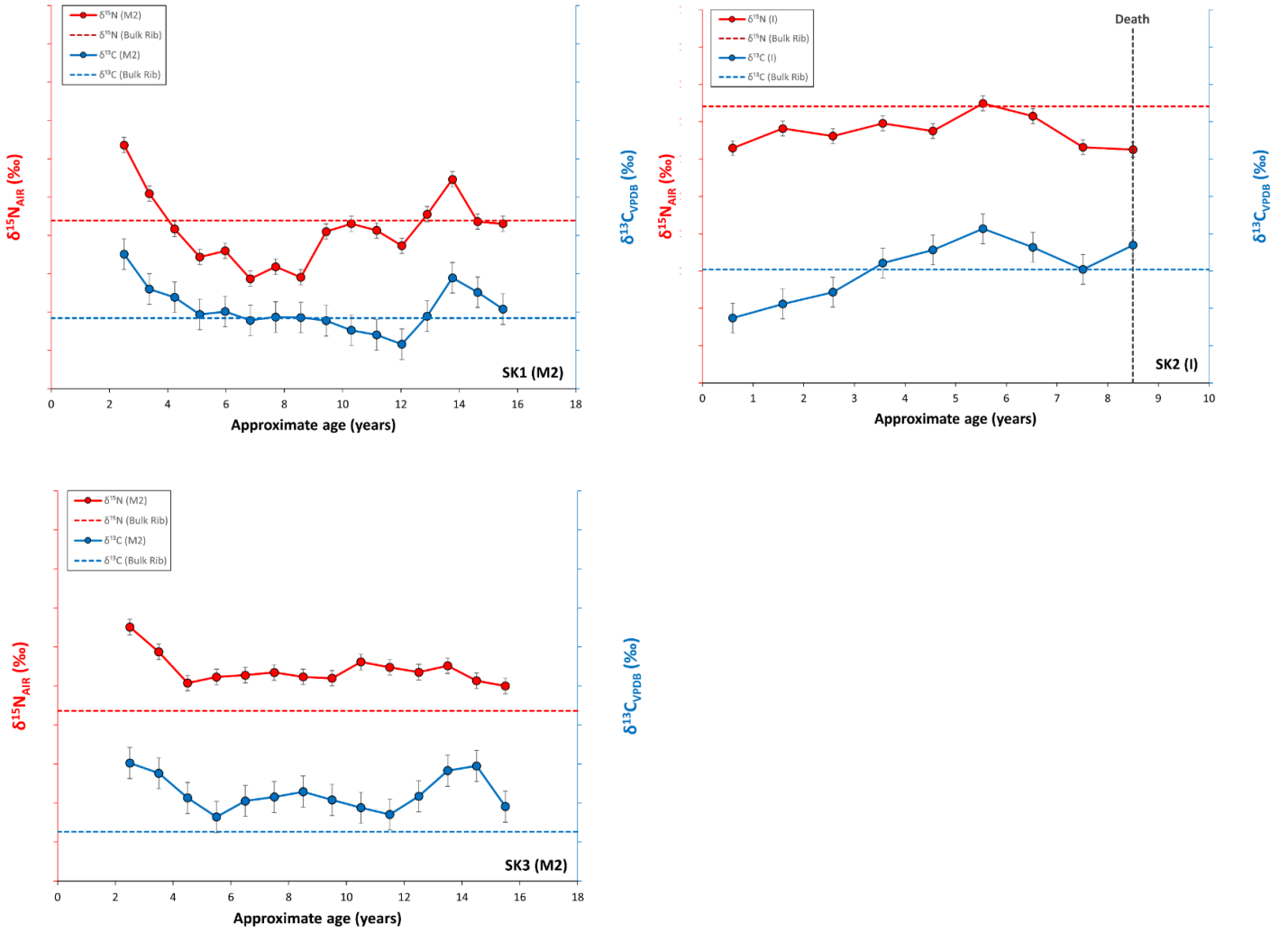


Figure 3: Incremental dentine $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ data for the Großmugl individuals plotted against age in years. The dashed red and blue straight lines across the plots indicate the average $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values obtained from the individuals rib collagen. For SK2, the vertical black dashed line represents the arrestation of tooth development for the incomplete incisor at the estimated age-at-death.

3. Assessing Geographical Origins

3.1 Oxygen isotope analysis

Oxygen incorporated into hydroxyapatite is predominantly derived from ingested fluids, the isotopic composition of which fluctuates due to climatic and environmental variables such as temperature, rainfall, altitude and latitude (Darling and Talbot, 2003). Therefore, oxygen isotopes ($\delta^{18}\text{O}$) measured in human tissues are an indirect reflection of the local meteoric water composition (Kohn, 1999). Oxygen undergoes

metabolic fractionation once ingested. Therefore, regression formulae must be applied to allow comparison with modern drinking water values in order to discern childhood geographical origins and palaeo-climate (Chenery et al., 2012; Fricke et al., 1995). In addition to this, $\delta^{18}\text{O}$ values can also be influenced by culturally mediated behaviour. The processing (boiling, brewing etc.) of a significant portion of an individual's drinking water before ingestion can result in higher than expected values, and as such, interpretation must be performed with caution (Brettell et al., 2012; Camin et al., 2008; Daux et al., 2008).

3.1.1 Materials and methods

Tooth enamel samples were cleaned and abraded to a depth of $>100\mu\text{m}$ using a diamond-tipped dental drill to remove dentine and surface contaminants. Powdered tooth enamel samples (c. 16 mg) were then collected on foil using a diamond-tipped burr and transferred to 1.5 mL microcentrifuge tubes. Samples were not pre-treated with an oxidising agent such as sodium hypochlorite or acetic acid, as they have been shown to cause isotopic shifts (Pellegrini and Snoeck 2016). Recent studies have deemed this step unnecessary for enamel pre-treatment (e.g., Balasse *et al.* 2020; Hodgkins *et al.* 2020). The samples were transferred to Iso Analytical for stable isotope analysis. Here, the samples were weighed into ExetainerTM tubes and flushed with 99.995% helium. Carbonate in the samples was converted to CO_2 by adding phosphoric acid and letting the sample sit overnight for the reaction to occur. Reference materials (IA-R022, NBS-18, and IA-R066) were prepared along the same methods. CO_2 from the samples was then analysed by Continuous Flow-Isotope Ratio Mass Spectrometry (CF-IRMS). The CO_2 was sampled from the ExetainerTM tubes into a continuously flowing He stream using a double holed needle. The CO_2 was resolved on a packed column gas chromatograph and the resultant chromatographic peak carried forward into the ion source of a Europa Scientific 20-20 IRMS where it was ionized and accelerated. Gas species of different mass were separated in a magnetic field then simultaneously measured using a Faraday cup collector array to measure the isotopomers of CO_2 at m/z 44, 45, and 46. The phosphoric acid used for digestion was prepared in accordance with Coplen et al. (1983) and was injected through the septum into the vials. All samples were run in duplicate. Analytical errors for the analysis were $\delta^{13}\text{C} \pm 0.2 \text{ ‰}$ (1 sd) and $\delta^{18}\text{O} \pm 0.2 \text{ ‰}$ (1 sd).

3.1.2 Results and interpretation

The Großmugl individuals' oxygen isotope data is presented in Table 2 and Figure 4, alongside comparative data from the early Iron Age western Hallstatt culture tumulus at Magdalenenberg, Germany (Oelze *et al.* 2012) and the Late Bronze Age hillfort at Stillfried an der March, Austria (Retzmann *et al.* 2020).

The Großmugl individuals' $\delta^{18}\text{O}$ values were measured in carbonate and converted to phosphate values (Chenery *et al.* 2012) and precipitation/drinking water values (Daux *et al.* 2008) to facilitate comparison with other published data. These $\delta^{18}\text{O}_{\text{phos}}$ values range from REDACTED to REDACTED with a median of REDACTED. SK1 and SK3's $\delta^{18}\text{O}_{\text{phos}}$ values differ by only 0.2‰ and are therefore within analytical error of each other, whilst SK2's $\delta^{18}\text{O}_{\text{phos}}$ value is 1.0‰ and 0.8‰ higher than SK1 and SK3, respectively. As oxygen isotope ratios can be influenced by factors such as temperature, altitude, rainfall levels, and latitude (Darling and Talbot 2003), the similar lower phosphate $\delta^{18}\text{O}$ values of SK1 and SK3 could suggest these individuals procured their water from a source with similar geographical conditions or lived during a period of similar climatic conditions. In contrast, SK2's higher phosphate $\delta^{18}\text{O}$ value may imply this individual obtained their water, or potentially originated, from an area with a different altitude, latitude, amount of rainfall, or temperature. Alternatively, SK2 may not be contemporaneous with the other two individuals and may instead have spent their childhood in the same area during a time of warmer climatic conditions (Darling and Talbot 2003). Regional and localised changes in climate are documented within the palaeo-environmental record across Europe during the Bronze Age and Iron Age (Molloy 2022). The higher $\delta^{18}\text{O}_{\text{phos}}$ value observed in SK2's enamel may also be influenced by the early developmental age of the permanent incisor in comparison to the permanent second molars. With development starting at around 7.5 months of age, the enamel of the permanent incisor may incorporate $\delta^{18}\text{O}$ from breast milk and yield a higher oxygen isotope ratio, as breast milk is often enriched in ^{18}O in comparison to the drinking water an individual consumes later in life (Chinique de Armas *et al.* 2022).

In the context of geographical origin, all of the Großmugl individuals' $\delta^{18}\text{O}$ values lie within the range expected for the site and are therefore consistent with having a local

childhood provenance. Lightfoot and O'Connell's (2016) map of regional modern precipitation oxygen isotopic values have been used to estimate the local drinking water value ($\delta^{18}\text{O}_{\text{dw}}$) range for Großmugl, which has been converted to phosphate values to be shown in Figure 4. The site and its wider region sit on a boundary between a zone of expected higher $\delta^{18}\text{O}_{\text{dw}}$ values (-10‰ to -8‰) and one of expected lower $\delta^{18}\text{O}_{\text{dw}}$ values (-12‰ to -10‰), making the estimated range of local $\delta^{18}\text{O}$ values quite large (-12‰ to -8‰). SK1 and SK3's $\delta^{18}\text{O}_{\text{dw}}$ values lie close to the lower end of this local range and both fall outside the 2 sd range for Großmugl when the analytical error and large uncertainties associated with oxygen conversion equations are considered. Therefore, whilst these two individuals have $\delta^{18}\text{O}$ values consistent with a local upbringing, their oxygen isotope data cannot rule out other potential residential origins in areas with lower $\delta^{18}\text{O}$ values such as the Alps to the west of Großmugl (Lightfoot and O'Connell 2016). SK2's $\delta^{18}\text{O}_{\text{dw}}$ value lies in the middle of the local range and remains within it at 2 sd, therefore suggesting this individual's oxygen isotope ratios are consistent with a childhood residence local to Großmugl.

However, as can be seen in Figure 4, the majority of the $\delta^{18}\text{O}$ values from the Magdalenenberg tumulus also lie within this estimated local range despite the individuals being inferred as having heterogeneous origins (Oelze *et al.* 2012). This comparison serves to emphasise that this estimated local range of $\delta^{18}\text{O}$ values is not exclusive to the site or Austria in general and can be found across vast areas of central and eastern Europe as well as Britain (Lightfoot and O'Connell). In the absence of other suitable comparative literature and oxygen isotope data from local samples, it is not possible to ascertain a more accurate local oxygen isotope range for Großmugl. Modern regional datasets such as Lightfoot and O'Connell (2016) are an appropriate alternative to exclude potential residential origins and infer regional locality. For instance, using this comparative dataset, it is possible to exclude potential residential origins for all three Großmugl individuals in most of western Europe, Italy and most of south-east Europe where higher $\delta^{18}\text{O}$ values are expected.

[REDACTED] Table 3: Measured carbonate ($\delta^{13}\text{C}_{\text{VPDB}}$ and $\delta^{18}\text{O}_{\text{VPDB}}$) and calculated $\delta^{18}\text{O}_{\text{VSMOW}}$ and drinking water values for the enamel samples from Großmugl

Skeleton	$\delta^{13}\text{C}_{\text{VPDB}}$ carbonate measured (‰)	$\delta^{18}\text{O}_{\text{VPDB}}$ carbonate measured (‰)	$\delta^{18}\text{O}_{\text{VSMOW}}$ carbonate calculated (‰)	$\delta^{18}\text{O}_{\text{VSMOW}}$ phosphate calculated (‰)	$\delta^{18}\text{O}_{\text{VSMOW}}$ precipitation calculated (‰)
SK1					
SK2					
SK3					

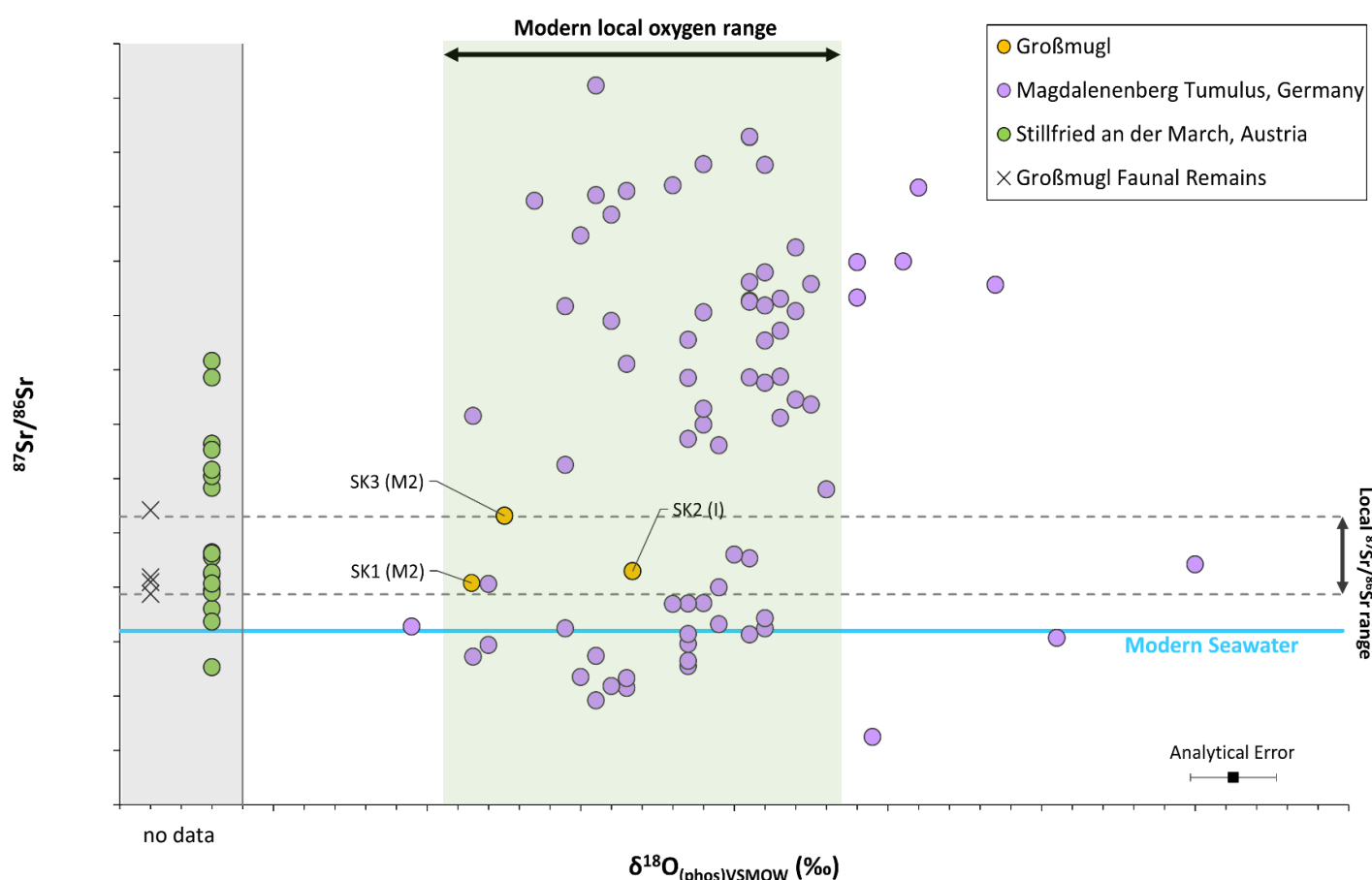


Figure 4: Großmugl $^{87}\text{Sr}/^{86}\text{Sr}$ and calculated $\delta^{18}\text{O}$ phosphate data alongside comparative data from Stillfried an der March, Austria (Retzmann *et al.* 2020) and the Magdalenenberg tumulus, Germany (Oelze *et al.* 2012). The horizontal dotted lines represent the bioavailable strontium isotope range for Großmugl (Retzmann *et al.* 2020). The shaded green box represents the oxygen isotope range expected for the site and its surrounding region (Lightfoot and O'Connell 2016). Oxygen error shown to 1σ , strontium errors are within the symbol.

3.2 Strontium isotope analysis

The isotope analyses of strontium ($^{87}\text{Sr}/^{86}\text{Sr}$) can provide information on the movements and mobility of past populations by identifying individuals who have different isotopic compositions to the geographic area in which they were found (Evans *et al.* 2012). Strontium isotopes offer a direct link between an individual and their geographic origin because strontium derives from bedrock and is transferred from the rock through soil, plants, and animals whilst still remaining indicative of the source rock (Bentley 2006). The strontium isotope ($^{87}\text{Sr}/^{86}\text{Sr}$) characteristics of plants and animals that eat these plants will vary in different regions depending on the relative contributions of strontium from different underlying rocks and the presence or absence of superficial drift deposits (Bentley 2006). Strontium becomes incorporated into the hydroxyapatite lattice of human bone through ingestion of food and water (Montgomery *et al.* 2010). Assuming that the majority of a population's food and drink is sourced locally, the strontium isotope composition in human skeletal material should then reflect the bioavailable strontium isotopes in their region of origin (Montgomery *et al.* 2007).

3.2.1 Materials and methods

Core enamel samples (c. 5 mg) from permanent second molars of SK1 and SK3 and a permanent incisor from SK2 were prepared for strontium isotope analysis using column chemistry methods outlined in Font *et al.* (2008) at the Arthur Holmes Isotope Geology Laboratory (AHIGL), Durham University. In brief, samples were digested overnight in 3M HNO_3 on a hotplate at 100°C before being loaded onto cleaned and preconditioned columns containing Eichrom strontium-specific resin. A purified Sr fraction was eluted from the column in 400µl H_2O and acidified with 15.5M HNO_3 to yield a 3% HNO_3 solution.

Following Sr purification, the size of the ^{86}Sr beam was tested for each sample to derive a dilution factor so that each sample yielded a beam size of approximately 25V ^{88}Sr to match the intensity of the isotopic reference material NBS987. Samples were aspirated using an ESI PFA-50 nebuliser coupled to a Glass Expansion Cinnabar micro-cyclonic spraychamber. Sr isotopes were measured using a static multi-collection routine with each measurement comprising a single block of 50 cycles with

an integration time of 4s per cycle (total analysis time ~3.5 minutes). Instrumental mass bias was corrected for using an $^{88}\text{Sr}/^{86}\text{Sr}$ ratio of 8.375209 (the reciprocal of the more commonly used $^{86}\text{Sr}/^{88}\text{Sr}$ ratio of 0.1194) and an exponential law. Corrections for isobaric interferences from Rb and Kr on ^{87}Sr and ^{86}Sr were performed using ^{85}Rb and ^{83}Kr as the monitor masses but were insignificant. In all samples the ^{85}Rb intensity was $< 1\text{mV}$ with an $^{85}\text{Rb}/^{88}\text{Sr}$ ratio of < 0.0003 (average 0.0001). ^{83}Kr was between 0.12 and 0.14mV in all samples. Samples were analysed during a single analytical session during which the average $^{87}\text{Sr}/^{86}\text{Sr}$ ratio and reproducibility for the international reference material NBS987 was 0.710248 ± 0.000009 (2σ ; $n = 13$). Maximum error based on internal precision of individual analysis and analytical reproducibility of the reference material is considered to be 0.000009 (2σ). Sr isotope data for samples is normalised to an 'accepted value for NBS987 of 0.710240.

Dentine samples from faunal remains recovered at Großmugl, including one permanent third molar from a pig and permanent second molars from three sheep, were also analysed following this method. The faunal dentine samples were analysed in a separate single analytical session, during which the average $^{87}\text{Sr}/^{86}\text{Sr}$ ratio and reproducibility for the international reference material NBS987 was 0.710255 ± 0.000017 (2σ ; $n = 11$). The $^{87}\text{Sr}/^{86}\text{Sr}$ data for the Großmugl fauna are presented in the Appendix (Table A4).

3.2.2 Results and interpretation

The Großmugl individuals' strontium isotope data is presented in Table 4 and Figure 4 alongside comparative data from Magdalenenberg (Oelze *et al.* 2012) and Stillfried an der March (Retzmann *et al.* 2020). The $^{87}\text{Sr}/^{86}\text{Sr}$ values from the tooth enamel of the Großmugl individuals range from REDACTED, with a median of REDACTED, which is within the expected range for Austria (Voerkelius *et al.* 2010). Tooth enamel strontium concentrations from these individuals ranged from REDACTED to REDACTED, with a median of REDACTED, and are all typical of archaeological human populations (Evans *et al.* 2012).

Großmugl is situated in the Molasse Basin which consists of mainly Cenozoic sands, gravels and marls. The site also closely borders the Waschberg Zone; a narrow nappe of Cenozoic sandstone with some outcrops of Jurassic limestone (Granado *et al.* 2016;

Gebhardt 2020). No strontium isotope data from modern or archaeological samples was available for Großmugl or the site's immediate local area. However, environmental samples from the Late Bronze Age hillfort at Stillfried an der March, around 46km east of Großmugl, have been used as a proxy for the local bioavailable strontium isotope range due to the site's similar underlying Cenozoic sedimentary geology. From this, the local bioavailable strontium isotope range for Großmugl has been estimated to lie between 0.7098 and 0.7113 (Retzmann *et al.* 2020). It is expected that people who source most of their food and drink from within regions of Cenozoic sands and marls would have strontium isotope ratios close to this range. The $^{87}\text{Sr}/^{86}\text{Sr}$ values from the dentine of the Großmugl fauna range from REDACTED to REDACTED (with a mean of REDACTED) and all mostly lie within this expected local range, with only one sheep sitting just outside (See Figure 4). As dentine is susceptible to diagenetic alteration in the burial environment and can exchange mineral and organic elements with the surrounding soil, these faunal dentine $^{87}\text{Sr}/^{86}\text{Sr}$ values can be used as a proxy for the labile strontium isotope range for the burial environment at Großmugl (Budd *et al.* 2000; Dauphin and Williams 2004; Montgomery *et al.* 2007; Kendall *et al.* 2018). As shown in Figure 4 the $^{87}\text{Sr}/^{86}\text{Sr}$ values for the enamel samples of all three Großmugl individuals plot within the expected local strontium range (Retzmann *et al.* 2020), with SK3 sitting on the upper boundary, and all lie within the local faunal range. These individuals therefore have strontium isotope ratios consistent with a childhood spent in the Großmugl area.

However, it is important to note that these $^{87}\text{Sr}/^{86}\text{Sr}$ values are not unique to Großmugl and can also be found in other regions with similar underlying geology such as areas of central and south-west England, southern Scotland, Hungary, Germany and elsewhere in central and northern Europe (Voerkelius *et al.* 2010; Evans *et al.* 2010). Notably, the strontium isotope ratios for the tooth enamel of SK1 and SK2 sit within a largely undiagnostic range of values that occur throughout much of Europe due to shared characteristics of the geological terrain (Montgomery *et al.* 2014). Consequently, although the three individuals have $^{87}\text{Sr}/^{86}\text{Sr}$ values consistent with a local childhood residence, Großmugl cannot be established as their only possible provenance. Areas with older, more heterogeneous and granitic lithologies to the southwest such as the Alps and the Bohemian Massif to the north of the site, can however be excluded as likely residential origins for the Großmugl individuals, as they

would be expected to produce much higher $^{87}\text{Sr}/^{86}\text{Sr}$ values exceeding 0.7120 (Oelze *et al.* 2012).

[REDACTED] Table 4: Measured tooth enamel $^{87}\text{Sr}/^{86}\text{Sr}$ values from the Großmugl individuals

Skeleton	Tooth	Sr ppm	$^{87}\text{Sr}/^{86}\text{Sr}$	2SE
SK1	M2			
SK2	I			
SK3	M2			

4. Discussion

Diet and mobility of three individuals from Großmugl were investigated using a range of isotopes to explore diet and migration throughout life. Bulk carbon and nitrogen isotope results show that all three individuals had a diet predominantly based on terrestrial C_3 resources, the carbon isotopes in their tooth enamel, which represents whole diet supports this interpretation. Examining the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ spacing between these individuals and contemporaneous animals from Austria suggests that they all had long-term diets predominantly based on terrestrial C_3 resources, with the inclusion of higher trophic level animal protein such as suckling pig or freshwater fish. Incremental dentine analysis highlights how SK1 and SK3 had relatively stable terrestrial C_3 diets throughout childhood, but both experienced periods of physiological or nutritional stress between the ages of 8 to 12 years. Although all three individuals appear to have eaten a predominantly terrestrial C_3 diet, SK2 has consistently higher nitrogen isotope values in their rib an incremental dentine profile. While it may be possible that this individual incorporated some marine protein into their diet it is likely that this difference is due to chronic physiological stress.

Mobility isotopes (Sr, O) and trace element analyses indicate that SK1 and SK3 grew up in a similar, if not the same location. Both individuals have strontium and oxygen isotope ratios consistent with Großmugl, and low lead and arsenic concentrations typical for the period. Although SK2 also has strontium and oxygen isotope ratios consistent with Großmugl (the slightly higher oxygen value likely due to breastfeeding),

their higher strontium concentration suggest they did not grow up in the same environment as SK1 and SK3. It is also important to note that strontium isotope ratios seen in all three of these individuals are not unique to Großmugl and can also be found in other regions with similar underlying geology such as Hungary, Germany and elsewhere in central and northern Europe.

In summary, the isotopic characteristics of these three individuals suggest local origins for SK1 and SK3, who both have consistently similar data for both their diet and geographic origins. However, SK2 is different. If contemporary with SK1 and SK3 then the differences in SK2's carbon, nitrogen and oxygen isotopes could be due to breastfeeding and chronic physiological stress. Alternatively, SK2 displays many of the isotopic characteristics of an individual from the Roman period, and if secure dating has not been carried out, radiocarbon dating is strongly recommended for this individual.

5. Conclusions

- The carbon isotope ratios from the Großmugl individuals are consistent with a predominantly terrestrial C₃ diet.
- Notably, the nitrogen isotope ratios from the Großmugl individuals are significantly higher than those observed in contemporaneous and Early Medieval populations in Germany and Austria. This may imply the use of crop manuring, consumption of freshwater fish and/or the inclusion of higher trophic level foods such as omnivorous animals (e.g., suckling pigs) within the diet.
- The incremental dentine profiles of the three individuals support the consumption of a primarily terrestrial C₃ diet during tooth formation in childhood, with some minor dietary changes visible in the profiles of SK1 and SK3.
- Periods of nutritional or physiological stress were identified in the profiles of each Großmugl individual. For SK2 in particular, the sustained high $\delta^{15}\text{N}$ values across the profile suggest this individual experienced continuous stress during tooth development. This is consistent with their estimated age-at-death in later childhood and the high $\delta^{15}\text{N}$ values observed in SK2's rib bone collagen.

- The oxygen isotope data of all three Großmugl individuals is consistent with a local origin to the site. SK1 and SK3's $\delta^{18}\text{O}$ values are very similar and could also be consistent with residential origins in areas with lower $\delta^{18}\text{O}$ values such as the Alps to the southwest of the site or they may have resided at Großmugl during a time with differing climatic conditions to SK2.
- All the Großmugl individuals have strontium isotope ratios consistent with a childhood spent local to the site, although residential origins in other areas with similar underlying geology cannot be ruled out. The faunal data was also consistent with a local origin.
- The strontium concentrations for the Großmugl individuals were consistent with archaeological humans with childhood residential origins at Großmugl or an area with similar underlying geology.

References

- AlQahtani, S., 2009. An Atlas of Dental Development and Eruption. London: Queen Mary College, University of London
- Ambrose, S.H., 1990. Preparation and Characterisation of Bone and Tooth Collagen for Isotopic Analysis. *Journal of Archaeological Science*, 17(1), pp. 431-451
- Ambrose, S.H., Noor, L., 1993. Experimental Evidence for the Relationship of the Carbon Isotope Ratios of Whole Diet and Dietary Protein to those of Bone Collagen and Carbonate. In Lambert JB and Grupe G (eds) *Prehistoric Human Bone Archaeology at the Molecular Level*. Berlin: Springer-Verlag, pp. 1-37
- Arriaza, B., Amarasiriwardena, D., Cornejo, L., Standen, V., Byrne, S., Bartkus, L., Bandak, B., 2010. Exploring Chronic Arsenic Poisoning in Pre-Columbian Chilean Mummies. *Journal of Archaeological Science*, 37(6), pp. 1274-1278
- Balasse, M., Renault-Fabregon, L., Gandois, H., Fiorillo, D., Gorczyk, J., Bacvarov, K., Ivanova, M., 2020. Neolithic Sheep Birth Distribution: Results from Nova Nadezhda (sixth millennium BC, Bulgaria) and a Reassessment of European Data with a new Modern Reference set Including Upper and Lower Molars. *Journal of Archaeological Science*, 118(1), pp. 105139
- Beaumont, J., Lee-Thorp, J., Montgomery, J., 2013. Childhood Diet: A Closer Examination of the Evidence from Dental Tissues Using Stable Isotope Analysis of Incremental Human Dentine. *Archaeometry*, 55(2), pp. 277-295
- Beaumont, J., Montgomery, J., 2015. Oral Histories: A Simple Method of Assigning Chronological Age to Isotopic Values from Human Dentine Collagen. *Annals of Human Biology*, 42(4), pp. 407-414
- Beaumont, J., Montgomery, J., 2016. The Great Irish Famine: Identifying Starvation in the Tissues of Victims Using Stable Isotope Analysis of Bone and Incremental Dentine Collagen. *PLoS ONE*, 11(8), pp. 1-21
- Bentley, R.A., 2006. Strontium Isotopes from the Earth to the Archaeological Skeleton: A Review. *Journal of Archaeological Method and Theory*, 13(1), pp. 135-187
- Bocherens, H., Drucker, D., 2003. Trophic Level Isotopic Enrichment of Carbon and Nitrogen in Bone Collagen: Case Studies from Recent and Ancient Terrestrial Ecosystems. *International Journal of Osteoarchaeology*, 13(1), pp. 46-53
- Bogaard, A., Heaton, T.H., Poulton, P., Merbach, I., 2007. The Impact of Manuring on Nitrogen Isotope Ratios in Cereals: Archaeological Implications for Reconstruction of Diet and Crop Management Practices. *Journal of Archaeological Science*, 34(3), pp. 335-343

- Bonsall, C., Cook, G., Pickard, C., McSweeney, K., Bartosiewicz, L., 2009. "Dietary Trends at the Mesolithic-Neolithic Transition in Northwest Europe" in Crombe, P., van Strydonck, M., Sergeant, J., Boudin, M., Bats, M., (eds.) *Chronology and Evolution within the Mesolithic of North-West Europe: Proceedings of an International Meeting, Brussels, May 30th-June 1st 2007*. Newcastle upon Tyne: Cambridge Scholars Publishing, pp. 539-562
- Bowen, H.J.M., 1988. Trace elements in biological samples. In *Techniques and Instrumentation in Analytical Chemistry* 8, pp.1-17. Elsevier.
- Brettell, R., Montgomery, J., Evans, J., 2012. Brewing and Stewing: The Effect of Culturally Mediated Behaviour on the Oxygen Isotope Composition of Ingested Fluids and the Implications for Human Provenance Studies. *Journal of Analytical Atomic Spectrometry*, 27(1), pp. 778-785
- Budd, P., Montgomery, J., Barreiro, B., Thomas, R.G., 2000. Differential Diagenesis of Strontium in Archaeological Human Dental Tissues. *Applied Geochemistry*, 15(5), pp. 687-694
- Camin, F., Perini, M., Colombari, G., Bontempo, L., Versini, G., 2008. Influence of Dietary Composition on the Carbon, Nitrogen, Oxygen and Hydrogen Stable Isotope Ratios of Milk. *Rapid Communications in Mass Spectrometry*, 22(1), pp. 1690-1696
- Chenery, C.A., Pashley, V., Lamb, A.L., Sloane, H.J., Evans, J., 2012. The Oxygen Isotope Relationship Between the Phosphate and Structural Carbonate Fractions of Human Bioapatite. *Rapid Communications in Mass Spectrometry*, 26(1), pp. 309-319
- Chinique de Armas, Y., Mavridou, A., Dominguez, J.G., Hanson, K., Laffoon, J., 2022. Tracking Breastfeeding and Weaning Practices in Ancient Populations by Combining Carbon, Nitrogen and Oxygen Stable Isotopes from Multiple Non-Adult Tissues. *PLOS ONE*, 17(2), pp. 1-28
- Coplen, T.B., Kendall, C., Hopple, J., 1983. Comparison of Stable Isotope Reference Samples. *Nature*, 302(5905), pp. 236-238
- Cox, G., Sealy, J., 1997. Investigating Identity and Life Histories: Isotopic Analysis and Historical Documentation of Slave Skeletons Found on the Cape Town Foreshore, South Africa. *International Journal of Historical Archaeology*, 1(3), pp. 207-224
- Darling, W.G., Talbot, J., 2003. The O and H Stable Isotope Composition of Freshwaters in the British Isles 1: Rainfall. *Hydrology and Earth System Sciences*, 7(1), pp. 161-181
- Dauphin, Y., Williams, C.T., 2004. Diagenetic Trends of Dental Tissues. *Comptes Rendus Palevol*, 3(6-7), pp. 583-590

- Daux, V., Lécuyer, C., Hèran, M., Amoit, R., Simon, L., Fourel, F., Martinaeu, F., Lynnerup, N., Richer, H., Escargueil, G., 2008. Oxygen Isotope Fractional Between Human Phosphate and Water Revisited. *Journal of Human Evolution*, 55(1), pp. 1138-1147
- DeNiro, M.J., 1985. Postmortem Preservation and Alteration of In Vivo Bone Collagen Isotope Ratios in Relation to Palaeodietary Reconstruction. *Nature*, 317(6040), pp. 806-809
- Dufour, E., Bocherens, H., Mariotti, A., 1999. Palaeodietary Implications of Isotopic Variability in Eurasian Lacustrine Fish. *Journal of Archaeological Science*, 26(6), pp. 617-627
- Evans, J., Montgomery, J., Wildman, G., Boulton, N., 2010. Spatial Variations in Biosphere $^{87}\text{Sr}/^{86}\text{Sr}$ in Britain. *Journal of the Geological Society*, 167, pp. 1-4
- Evans, J., Chenery, C., Montgomery, J., 2012. A Summary of Strontium and Oxygen Isotope Variation in Archaeological Human Tooth Enamel Excavated from Britain. *J. Anal. AT. Spectrom.*, 27(1), pp. 754-764
- Fahy, G.E., Deter, C., Pitfield, R., Miskiewicz, J.J., Mahoney, P., 2017. Bone Deep: Variation in Stable Isotope Ratios and Histomorphometric Measurements of Bone Remodelling within Adult Humans. *Journal of Archaeological Science*, 87(1), pp. 10-16
- Font, L., Davidson, J.P., Pearson, D.G., Nowell, G.M., Jerram, D.A., Ottley, C.J., 2008. Sr and Pb Isotope Micro-Analysis of Plagioclase Crystals from Skye Lavas: An Insight into Open-System Processes in a Flood Basalt Province. *Journal of Petrology*, 49(8), pp. 1449-1471
- Fraser, R., Bogaard, A., Heaton, T., Charles, M., Jones, G., Christensen, B.T., Halstead, P., Merbach, I., Poulton, P.R., Sparkes, D., Styring, A.K., 2011. Manuring and Stable Nitrogen Isotope Ratios in Cereals and Pulses: Towards a New Archaeobotanical Approach to the Inference of Land Use and Dietary Practices. *Journal of Archaeological Science*, 38(10), pp. 2790-2804
- Fuller, B.T., Fuller, J.L., Sage, N.E., Harris, D.A., O'Connell, T.C., Hedges, R.E.M., 2005. Nitrogen Balance and $\delta^{15}\text{N}$: Why You're not What You Eat During Nutritional Stress. *Rapid Communications in Mass Spectrometry*, 19(18), pp. 2497-2506
- Fricke, H. C., O'Neill, J.R., Lynnerup, N., 1995. Oxygen Isotope Composition of Human Tooth Enamel from Medieval Greenland: Linking Climate and Society. *Geology*, 23(1), pp. 869-872

Froehle, A.W., Kellner, C.M., Schoeninger, M.J., 2010. FOCUS: Effect of Diet and Protein Source on Carbon Stable Isotope Ratios in Collagen: Follow up to. *Journal of Archaeological Science*, 37(10), pp. 2662-2670

Gebhardt, H., 2020. Late Jurassic Foraminifera from the Southern Waschberg-Zdanice Unit (Klentnice Beds, Lower Austria). *Austrian Journal of Earth Sciences*, 113(2), pp. 155-168

Granado, P., Thöny, W., Carrera, N., Gratzer, O., Strauss, P., Muñoz, J.A., 2016. Basement-Involved Reactivation in Foreland Fold-and-Thrust Belts: The Alpine-Carpathian Junction (Austria). *Geological Magazine*, 154(5-6), pp. 1110-1135

Hatch, K.A., Crawford, M.A., Kunz, A.W., Thomsen, S.R., Eggett, D.L., Nelson, S.T., Roeder, B.L., 2006. An Objective Means of Diagnosing Anorexia Nervosa and Bulimia Nervosa using Using $^{15}\text{N}/^{14}\text{N}$ and $^{13}\text{C}/^{12}\text{C}$ Ratios in Hair. *Rapid Communications in Mass Spectrometry*, 20(22), pp. 3367-3373

Haubner, R., Strobl, S., 2020. The Copper-Arsenic Eutectic and the Cu_3As Phase. *Defect and Diffusion Forum*, 405, pp. 19-25

Hawksley, L. 2016. 'Bitten by Witch Fever: Wallpaper and Arsenic in the Victorian Home'. The National Archives Thames and Hudson. London

Hedges, R.E., Clement, J.G., Thomas, C.D.L. and O'Connell, T.C., 2007. Collagen turnover in the adult femoral mid-shaft: Modelled from anthropogenic radiocarbon tracer measurements. *American Journal of Physical Anthropology: The Official Publication of the American Association of Physical Anthropologists*, 133(2), pp. 808-816.

Hodgkins, J., Marean, C.W., Venter, J.A., Richardson, L., Roberts, P., Zech, J., Difford, M., Copeland, S.R., Orr, C.M., Keller, H.M., Fahey, B.P., 2020. An Isotopic Test of the Seasonal Migration Hypothesis for Large Grazing Ungulates Inhabiting the Palaeo-Agulhas Plain. *Quaternary Science Reviews*, 106221

Jay, E., 2009. Breastfeeding and Weaning Behaviour in Archaeological Populations: Evidence from the Isotopic Analysis of Skeletal Materials. *Childhood in the Past*, 2(1), pp. 163-178

Jay, M., Richards, M.P., 2006. Diet in the Iron Age Cemetery Population at Wetwang Slack, East Yorkshire, UK: Carbon and Nitrogen Stable Isotope Evidence. *Journal of Archaeological Science*, 33(5), pp. 653-662

Jim, S., Ambrose, S.H., Evershed, R.P., 2004. Stable Carbon Isotopic Evidence for Differences in the Dietary Origin of Bone Cholesterol, Collagen and Apatite: Implications for their use in Palaeodietary Reconstruction. *Geochimica et Cosmochimica Acta*, 68(1), pp. 61-72

- Kellner, C.M., Schoeninger, M.J., 2007. A Simple Carbon Isotope Model for Reconstructing Prehistoric Human Diet. *American Journal of Physical Anthropology*, 133(4), pp. 1112-1117
- Kendall, C., Eriksen, A.M., Kontopoulos, I., Collins, M.J., Turner-Walker, G., 2018. Diagenesis of Archaeological Bone and Tooth. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 491, pp. 21-37
- Kim, S.T., Coplen, T.B., Horita, J., 2015. Normalisation of Stable Isotope Data for Carbonate Minerals: Implementation of IUPAC Guidelines. *Geochimica et cosmochimica acta*, 158(1), pp. 276-289
- Kohn, M.J., 1999. You are what you eat. *Science*, 283(1), pp. 335-336
- Kohn, M. J., & Moses, R. J. 2013. Trace element diffusivities in bone rule out simple diffusive uptake during fossilization but explain in vivo uptake and release. *Proceedings of the National Academy of Sciences of the United States of America*, 110(2), pp. 419–424.
- Lee-Thorp, J.A., Sealy, J.C., Van Der Merwe, N.J., 1989. Stable Carbon Isotope Ratio Differences Between Bone Collagen and Bone Apatite, and their Relationship to Diet. *Journal of Archaeological Science*, 16(6), pp. 585-599
- LeHuray, J.D., Schutkowski, H., 2005. Diet and Social Status during the La Tène Period in Bohemia: Carbon and Nitrogen Stable Isotope Analysis of Bone Collagen from Kutna Hora-Karlovy and Radoševice. *Journal of Anthropological Archaeology*, 24(2), pp. 135-147
- Lightfoot, E., O'Connell, T., 2016. On the Use of Biomineral Oxygen Isotope Data to Identify Human Migrants in the Archaeological Record: Intra-Sample Variation, Statistical Methods and Geographical Considerations. *PLOS ONE*, 11(4), pp. 1-29
- Longman, J., Veres, D., Finsinger, W., Ersek, V., 2018. Exceptionally High Levels of Lead Pollution in the Balkans from the Early Bronze Age to the Industrial Revolution. *PNAS*, 115(25), pp. 5661-5668
- Mekota, A., Grupe, G., Ufer, S., Cuntz, U., 2006. Serial Analysis of Stable Nitrogen and Carbon Isotopes in Hair: Monitoring Starvation and Recovery Phases of Patients Suffering from Anorexia Nervosa. *Rapid Communications in Mass Spectrometry*, 20(10), pp. 1604-1610
- Millard, A.R., Montgomery, J., Trickett, M., Beaumont, J., Evans, J., Chenery, S., 2014. "Childhood Lead Exposure in the British Isles During the Industrial Revolution", in Zuckerman, M.K. (eds.) *Modern Environments and Human Health: Revisiting the Second Epidemiological Transition*. Oxford: Wiley-Blackwell, pp. 279-300

- Minigawa, M., Wada, E., 1984. Stepwise Enrichment of $\delta^{15}\text{N}$ Along Food Chains: Further Evidence and the Relation Between $\delta^{15}\text{N}$ and Animal Age. *Geochimica et cosmochimica acta*, 48(5), pp. 1135-1140
- Mödlinger, M., Trebsche, P., Sabatani, B., 2021. Melting, Smelting, and Recycling: A Regional Study around the Late Bronze Age Mining Site of Prigglitz-Gasteil, Lower Austria. *PLOS ONE*, 16(7), pp. 1-33
- Molloy, B., 2022. Was There a 3.2 ka Crisis in Europe? A Critical Comparison of Climatic, Environmental, and Archaeological Evidence for Radical Change During the Bronze Age-Iron Age Transition. *Journal of Archaeological Research*, 30, pp. 1-64
- Montgomery, J., Evans, J., Cooper, R., 2007. Resolving Archaeological Populations with Sr-Isotope Mixing Models. *Applied Geochemistry*, 22(7), pp. 1502-1514
- Montgomery, J., 2010. Passports from the Past: Investigating Human Dispersals Using Strontium Isotope Analysis of Tooth Enamel. *Annals of Human Biology*, 27(3), pp. 325-346
- Montgomery, J., Evans, J., Chenery, S., Pashley, V., Killgrove, K., 2010. "Gleaming White and Deadly": Using Lead to Track Human Exposure and Geographic Origins in the Roman Period in Britain. *Journal of Roman Archaeology: Supplementary Series*, Suppl. 78(1), pp. 199-226
- Montgomery, J., Evans, J., 2013. "The Contribution of Skeletal Isotope Analysis to Understanding the Bronze Age in Europe" in Fokkens, H., Harding, A. (eds.) *The Oxford Handbook of the European Bronze Age*. Oxford: Oxford University Press, pp. 179-196
- Montgomery, J., Grimes, V., Buckberry, J., Evans, J., Richards, M., Barrett, J., 2014. Finding Vikings with Isotope Analysis: The View from Wet and Windy Islands. *Journal of the North Atlantic*, Special Volume 7, pp. 54-70
- Moore, J., Thornton, C., Montgomery, J., 2023. Trace Element Study of 15 Individuals from a mid-late 19th Century Cemetery in New Covent Garden Market, London. *Unpublished specialist report*. AIPRL, Archaeology Department, Durham University
- Mora, A., 2022. Stable Carbon and Nitrogen Isotope Analysis of Archaeological Human Hair: Reconstructing Diet and Health of Ancient Individuals. *Journal of Archaeological Science: Reports*, 43(1), 103439
- Murray, M.L., Schoeninger, M.J., 1988. "Diet, Status, and Complex Social Structure in Iron Age Central Europe: Some Contributions of Bone Chemistry" in Gibson, B.,

Geselowitz, M. (eds.) *Tribe and Polity in Late Prehistoric Europe*, London: Plenum Press, pp. 155-176

Oakberg, K., Levy, T., Smith, P., 2000. A Method for Skeletal Arsenic Analysis, Applied to the Chalcolithic Copper Smelting Site of Shiqmim, Israel. *Journal of Archaeological Science*, 27(1), pp. 895-901

O'Connell, T. C., & Hedges, R. E., 1999. Isotopic comparison of hair and bone: archaeological analyses. *Journal of Archaeological Science*, 26(6), 661-665

Oelze, V.M., Koch, J.K., Kupke, K., Nehlich, O., Zauner, S., Wahl, J., Weise, S.M., Rieckhoff, S., Richards, M.P., 2012. Multi-Isotopic Analysis Reveals Individual Mobility and Diet at the Early Iron Age Monumental Tumulus of Magdalenenberg, Germany. *American Journal of Physical Anthropology*, 148(1), pp. 406-421

Pellegrini, M., Snoeck, C., 2016. Comparing Bioapatite Carbonate Pre-Treatments for Isotopic Measurements: Part 2 – Impact on Carbon and Oxygen Isotope Compositions. *Chemical Geology*, 420(1), pp. 88-96

Radivojevic, M., Roberts, B.W., Pernicka, E., Stos-Gale, Z., Martinon-Torres, M., Rehren, T., Bray, P., Brandherm, D., Ling, J., Mei, J., Vandkilde, H., Kristiansen, K., Shennan, S., Broodbank, C., 2018. The Provenance, Use, and Circulation of Metals in the European Bronze Age: The State of Debate. *Journal of Archaeological Research*, 27, pp. 131-185

Retzmann, A., Kriechbaum, A.M., Griebel, M., Wiltschke-Schrotta, K., Teschler-Nicola, M., Irrgeher, J., Prohaska, T., 2020. Sr Isotope Analysis of Human Remains from Settlement Pits at Stillfried/March. Reappraising Diagenetic Changes. *Archaeologia Austriaca*, 104, pp. 53-87

Schoeninger, M.J., DeNiro, M.J., 1984. Nitrogen and Carbon Isotopic Composition of Bone Collagen from Marine and Terrestrial Animals. *Geochimica et Cosmochimica acta*, 48(4), pp. 625-639

Simpson, R., Cooper, D.M.L., Swanston, T., Coulthard, I., Varney, T.L., 2021. Historical Overview and New Directions in Bioarchaeological Trace Element Analysis: A Review. *Archaeological and Anthropological Sciences*, 13(1), 24

Sponheimer, M., 1999. Isotopic Ecology of the Makapansgat Limeworks Fauna [Unpublished PhD Thesis]. New Jersey: Rutgers University.

Swaine, D.J., 2000. Why trace elements are important. *Fuel Processing Technology*, 65, pp. 21-33.

Towers, J., 2013. An Isotopic Investigation into Calving Seasonality, Diet and Dairying in British Prehistoric Cattle [PhD Thesis]. Bradford: University of Bradford

Van Klinken, G.J., 1999. Bone Collagen Quality Indicators for Palaeodietary and Radiocarbon Measurements. *Journal of Archaeological Science*, 26(1), pp. 687-695

van Klinken, G. J., van der Plicht, H., & Hedges, R. E. M. (1994). Bond 13C/12C ratios reflect (palaeo-)climatic variations. *Geophysical Research Letters*, 21(6), pp. 445-448.

Voerkelius, S., Lorenz Gesine, D., Rummel, S., Quézel, C.R., Heiss, G., Baxter, M., Brach-Papa, C., Deters-Itzelsberger, P., Hoelzl, S., Hoogewerff, J., Ponzevera, E., Van Bocxstaele, M., Ueckermann, H., 2010. Strontium Isotopic Signatures of Natural Mineral Waters, the Reference to a Simple Geological Map and its Potential for Authentication of Food. *Food Chemistry*, 118(4), pp. 933-940

Wells, P.S., 1986. Investigating the Variability Among Small Settlements: Excavations at Altdorf, Bavaria, West Germany. *Journal of Field Archaeology*, 13(1), pp. 273-281

The “Furry Beaker Man”

***An Isotopic Investigation of a Bronze Age Cist Burial
Found at Oakslaw near Rock, Northumberland***



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Abstract

A rescue excavation at Oakslaw, in the Northumbrian town of Rock recovered the remains of a skeleton buried in a cist with a beaker vessel covered in an unusual fibrous material. The Early Bronze Age date of these remains raised the possibility of including this “Furry Beaker Man” within the Beaker People Project as the first example of an individual excavated in North-East England within the database. Consequently, an osteological analysis was performed to re-assess the previous biological sex and age-at-death estimations for the individual, as well as a multi-isotope study to reconstruct their mobility and diet. This involved strontium and oxygen isotope analysis of the enamel of the upper right canine and upper right third molar, and carbon and nitrogen isotope analysis of incremental dentine collagen and bulk bone. Trace element concentrations of strontium and lead were also obtained from the teeth. A probable male sex and age-at-death estimation between 18-25 based on the partial fusion of the sternal epiphysis of the right clavicle was concluded from the osteological analysis. The $^{87}\text{Sr}/^{86}\text{Sr}$ ratios and $\delta^{18}\text{O}_\text{p}$ values of the tooth enamel indicated a likely local origin within the region of varied geology surrounding Rock, whilst the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values in the dentine and bulk bone collagen suggested a probable omnivorous terrestrial diet with no significant marine resource consumption as identified for the majority of the Beaker People Project samples. The Oakslaw individual therefore likely represents a local individual to the North-East who possibly moved throughout the region during their lifetime before their burial at Rock and consumed a diet very similar to other contemporary populations across Britain, thus supporting the possibility of using these results to create another location group within the Beaker People Project which can conquer the regional gap and be expanded upon in the future.

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1. Introduction

Known to have been inhabited since the Mesolithic era and witnessing continuous occupation throughout the succeeding prehistoric periods (Waddington *et al.* 2005), the North-East of England, and the northern-most county of Northumberland in particular, are rich in archaeological sites and finds, and are especially valuable to our understanding of life during prehistory. Despite this supposed abundance, however, very little is known about the lifestyles of the Late Chalcolithic and Early Bronze Age (EBA) populations within the Northumbrian landscape, with this period defined here as lasting between 2500-1500 BC following Parker Pearson and colleagues' Beaker People Project (BPP) publication (2019). Hence, the accidental discovery of a cist burial of suspected EBA date containing a single inhumation (Figure 1) at Oakslaw in Rock, Northumberland in 2017 (Carlton 2018) provided a unique opportunity to explore the life history of this individual, including their mobility and dietary behaviours. This burial was radiocarbon dated to 2200-2031 cal BC within a 95.4% probability range (SUERC-102217) placing it within the EBA period as supported by the presence of a Beaker vessel beside the skull (Carlton 2018) and the east to west burial orientation with the head positioned to the south, typical of this period (Fowler 2013: 231). Two osteological analyses have been undertaken on the remains, with both concluding a male biological sex and an age-at-death estimation between 17-25 years old (Carlton 2018), despite the body's position in the cist lying on its right side with the head facing west usually being associated with female burials (Dyer 2002). An extensive fibrous plant growth also covered the skeleton's left side (Carlton 2018), which was initially proposed to be caused by a perishable shroud or wrapping (Fowler 2013), but was confirmed to be intrusive 16th-18th plant material by radiocarbon dating (SUERC 102264). The Oakslaw individual, affectionately named the "Furry Beaker Man", was thus the focus of this study to shed light on the life history of EBA populations in the North-East.



Figure 1: *In-situ* photographs of the individual buried in the cist at Oakslaw. Left: As found, without the bell beaker which was removed when the burial was discovered by a member of the public. Right: With the Beaker pot replaced at the head of the individual. The plant growth on the left side of the skeleton can be seen on both pictures as the dark brown staining on the bones (Carlton 2018)

1.1 Site Background and Importance

This unusual burial is even more significant considering the survival and preservation of the cist and remains on low lying, intensively cultivated land (Carlton 2018). Typically, the acidic soil in Northumberland favours against bone preservation (Figure 2), as evidenced by the preservation of only skull fragments in a cist found 6km from Rock at Howick (Waddington *et al.* 2005). However, the skeletal preservation of the Oakslaw individual almost matches that of other burials found within the higher grounds of the Cheviots, where entire cairnfields have been preserved by favourable soil conditions and little agricultural disturbance (Carlton 2018). Therefore, this uncommon find from Rock offered the chance to investigate EBA activities within eastern Northumberland (Figure 3), and the opportunity to combat the regional gap for North-East England within the BPP (Parker Pearson *et al.* 2019).

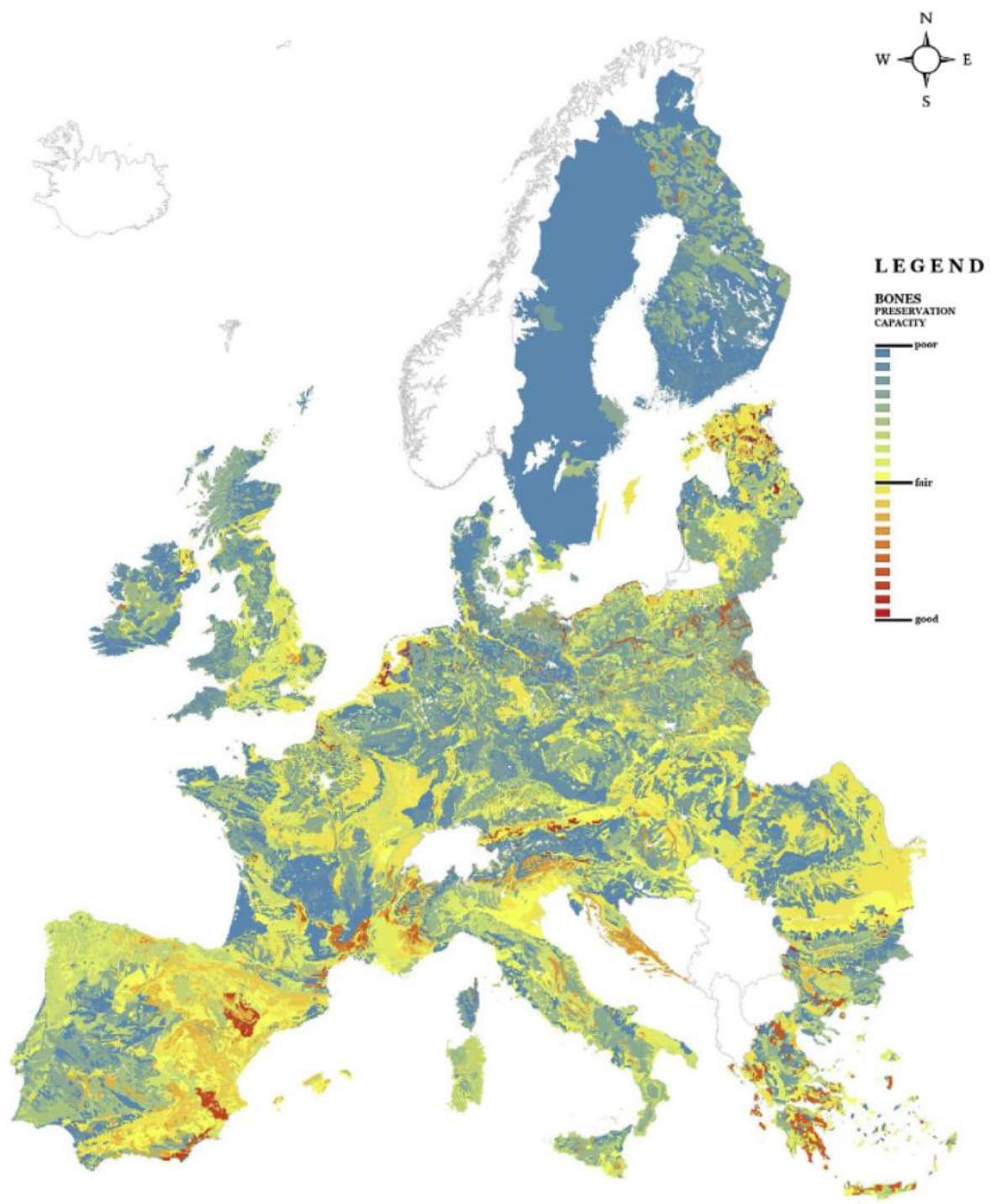


Figure 2: A map of Europe and key showing the expected levels of preservation of bones, teeth and shells in soils of different regions. The North-East of England typically has poor preservation of these materials. (Kibblewhite *et al.* 2015: 255)

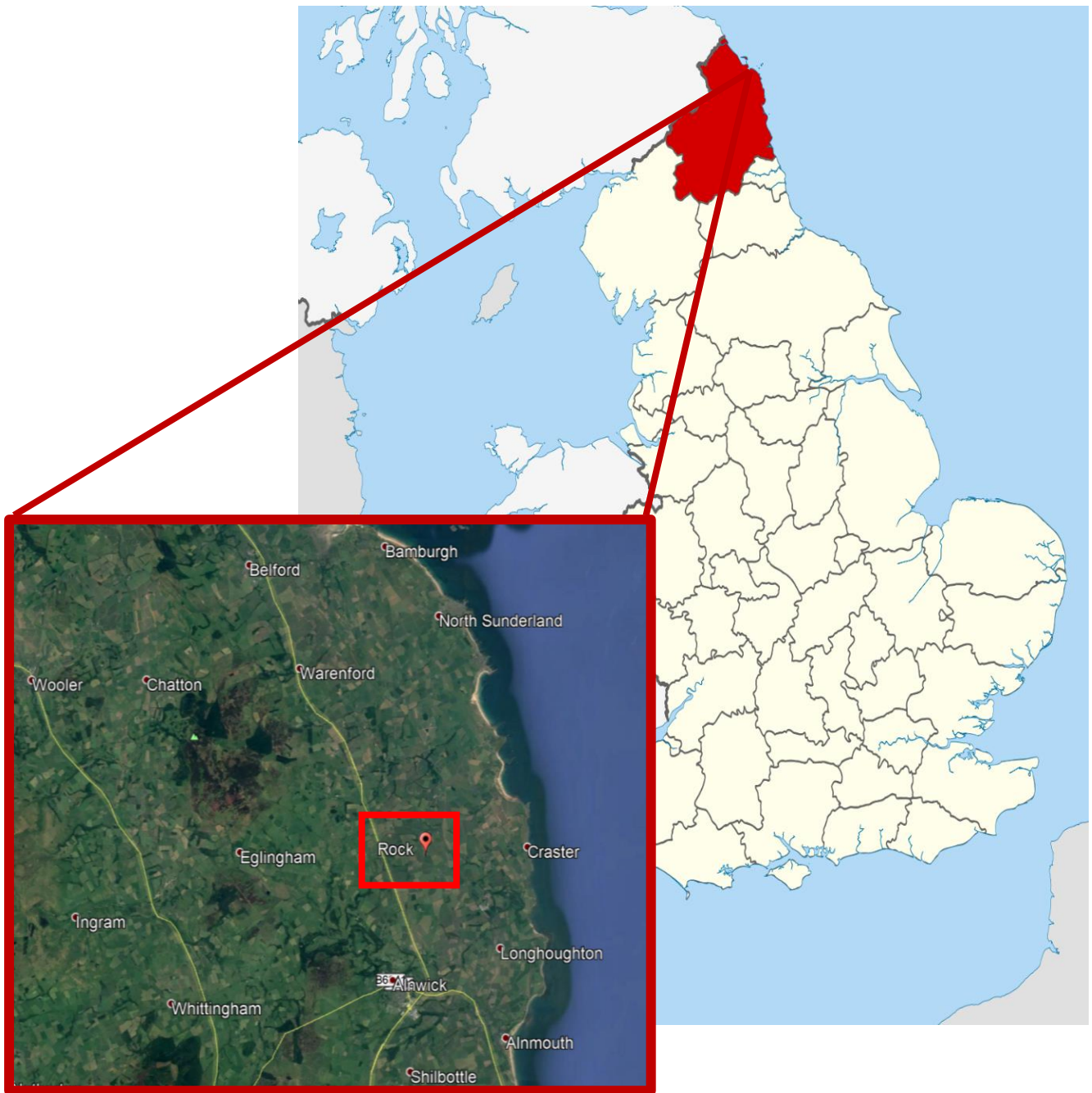


Figure 3: The location of Rock where the cist was found in the northern English county of Northumberland. The map notes its close proximity to the modern coast. (Goggle Earth Pro 2018)

1.2 Aims and Objectives

Taking into account the context of the burial and its potential importance within the wider field of EBA research, three aims were developed for this study. These were:

- To gain an insight into the life history of the Oakslaw individual and investigate their lifetime movements, dietary behaviour, and biological identity.

- To contribute new knowledge about mobility, diet, and lifestyle in the EBA to the Beaker People Project in order to combat the regional gap within the database for North-East England.
- To assess the implications of the inferences made about the Oakslaw individual on our overall understanding of migration, subsistence, and identity in the EBA period in Britain.

These aims were consequently hoped to be achieved within this work by fulfilling a set of carefully constructed objectives, which were:

- To perform, analyse, and interpret the results of stable isotope analysis undertaken on samples from the Oakslaw individual. This included:
 - Strontium, oxygen, and carbon isotope ratio measurements from tooth enamel samples.
 - Carbon and nitrogen isotope ratio measurements from bulk bone and incremental dentine collagen samples.
- To undertake trace element analysis on enamel from the Oakslaw individual to measure concentrations of strontium and lead within the samples.
- To compare the results of the stable isotope and trace element analyses with the Beaker People Project comparative database to form inferences about this individual's geographical origin, diet, and potential lifetime movements within the wider context of the British Late Chalcolithic/EBA burial population.
- To reassess the two previous osteological analyses to attempt to confirm the biological sex, estimated age-at-death, and stature of the Oakslaw individual.

2. The Beaker People Project

The BPP is the main comparative dataset used here to contextualise the Oakslaw individual's isotope analysis results, covering the period 2500-1500 BC (Parker Pearson *et al.* 2019a). The isotope database was produced to improve understanding of the emergence of the Beaker culture in Britain and has shown that the British Chalcolithic and EBA saw significant levels of mobility within Britain, generating a likely underestimated conclusion that 41% of the sampled population were possibly non-local to the place they were buried (Parker Pearson *et al.* 2016; Montgomery *et al.* 2019a). Carbon and nitrogen isotope data (Jay and Richards

2019) was also available for the sample population to make inferences about diet, thus emphasising the suitability of applying this comparative dataset to the analysis of the Oakslaw individual. Furthermore, as no individuals excavated from North-East England were included within this dataset, it was hoped that the Oakslaw individual's isotope analysis results could complement the BPP and expand its geographical coverage.

2.1 Research Questions

In the context of this existing research, it is clear that this curious and rare example of a well-preserved EBA cist burial from the north-east of England has significant potential to contribute new and essential knowledge to both the BPP database and our general understanding of the lifestyles and activities of the “Beaker People” of Britain. Hence, to further facilitate the achievement of this study's aims and objectives, and to acknowledge the questions left unanswered by the current state of research, the following research questions were purposefully selected to be answered throughout this work:

- 1) What can the combination of stable isotope analysis, osteological assessment, and a comparative literature review uncover about this individual's life and death?
- 2) How can this investigation of the Oakslaw individual shed light on the lifetime activities of EBA populations in North-East England?
- 3) What is the significance of this individual and their burial, and how can their study contribute to our overall understanding of EBA Britain?

3. Stable Isotope Analysis

Due to the ambitious nature of the content covered in this study, the principles underpinning stable isotope analysis and its use in studying migration and reconstructing diets are presented in Appendix I.

4. Materials and Methods

4.1 Osteological Re-assessment

The skeletal remains recovered from the cist were obtained with permission from The Archaeological Practice Ltd., Newcastle, and were analysed in the Fenwick Human

Osteology Laboratory, Durham University. An osteological re-assessment was conducted to review the results of previous analyses initially performed by Sanita Nezirovic and followed more comprehensively by Michelle Gamble (Carlton 2018), which identified the inhumed individual as a young adult male aged between 17-25 years. A skeletal inventory adapted from Holst (2010) was compiled to record the remains and is presented in Appendix II. Surface preservation was assessed using subjective observations of the remains, particularly focussed on the presence and damage to the bone cortex, following McKinley's (2004) recording system range from 0-5+, where 0 represents unmodified bone in an excellent state of preservation and 5+ describes heavily eroded, morphologically altered bone in very poor preservation condition. The skeleton's completeness was assessed visually and recorded as a percentage where a higher value indicates a more complete skeleton. Degree of fragmentation was also recorded subjectively using a range from 'minimal' to 'extreme', where 'minimal' represented little or no fragmentation of the bones and 'extreme' represented extensive breaking of most bones into multiple small pieces. Together, these features were examined to facilitate sample selection for isotopic analysis and assess which metric and visual analyses were possible (Brickley 2004: 6-7), with the aim of recording as much information as possible about this individual who was lifted in the context of a rescue excavation, for future study.

To compare observations made here with those of the previous osteological assessments (Gamble in Carlton 2018), the same methods for age-at-death, biological sex, and living stature estimation were used. The individual's age-at-death was estimated following recommended methods from Buikstra and Ubelaker (1994), and Schaefer and colleagues (2009), as well as dental wear patterns from Brothwell (1981). An approximate age range was produced, as the different techniques such as assessing bone development and degeneration, epiphyseal fusion, and dental attrition each produce different age-at-death estimations which cannot be refined to a single exact age (Cox 2000). Biological sex was inferred from sexually dimorphic features of the skull (Buikstra and Ubelaker 1994; Schwartz 1995; White and Folkens 2005), although it must be noted that the pelvis, which is the most accurate skeletal element for sex determination due to its high degree of sexual dimorphism (Mays 2010), was not preserved. Stature was estimated from equations using long bone length (Trotter 1970). Lastly, evidence of pathology and non-metric traits was also identified as part of the standard human remains recording guidelines (Brickley and McKinley 2004).

4.2 Dental Preservation and Sample Selection

As evident in the skeletal inventory, all 32 permanent teeth were identified during osteological analysis, with their stages of wear and pathology recorded according to recognised standards (Connell 2004; Roberts and Connell 2004). The upper right third molar (RM³) and upper right permanent canine (RC⁻) were removed from the maxilla for isotopic analysis (see Figures 4 and 5). This was noted on the recording form and a label was placed with the skeleton as a record of the work undertaken. Table 1 documents the interpreted wear stages for these two teeth adhering to Brothwell's (1981) descriptions and reference diagrams (Figure 6), as well as the presence and severity of calculus. No significant pathologies such as dental caries, periapical lesions including dental abscesses (Ogden 2008), and enamel hypoplasia were identified in the teeth.

Table 1: The stages of wear for both teeth as well as the presence and severity of calculus are recorded here based on Brothwell's (1981) observations, with the addition of 'flecks' to record small calculus deposits that were deemed less extensive than Brothwell's 'slight' category. The surface the observed calculus is present on is also noted.

Tooth	Wear stage (Brothwell 1981)	Calculus	Calculus Severity	Calculus Position
RM ³	1	Absent	-	-
RC ⁻	3	Present	Flecks	Mesial

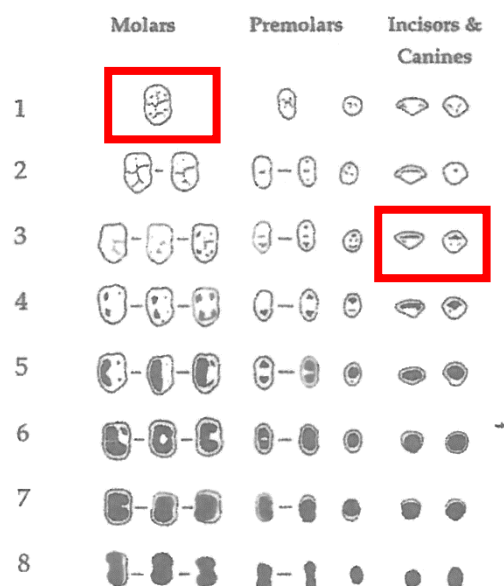


Figure 6: These diagrams were used to infer the wear stages of the teeth. The highlighted stages (red) serve as a graphical depiction of the wear stages inferred and presented in Table 1 (Smith 1984)



Figure 4: Record photographs for the RM³ demonstrating lack of wear on the occlusal surface (top left), length and overall appearance (lateral view: top right), and the incomplete apical closure (root apex: bottom) (Photos taken by author 202)

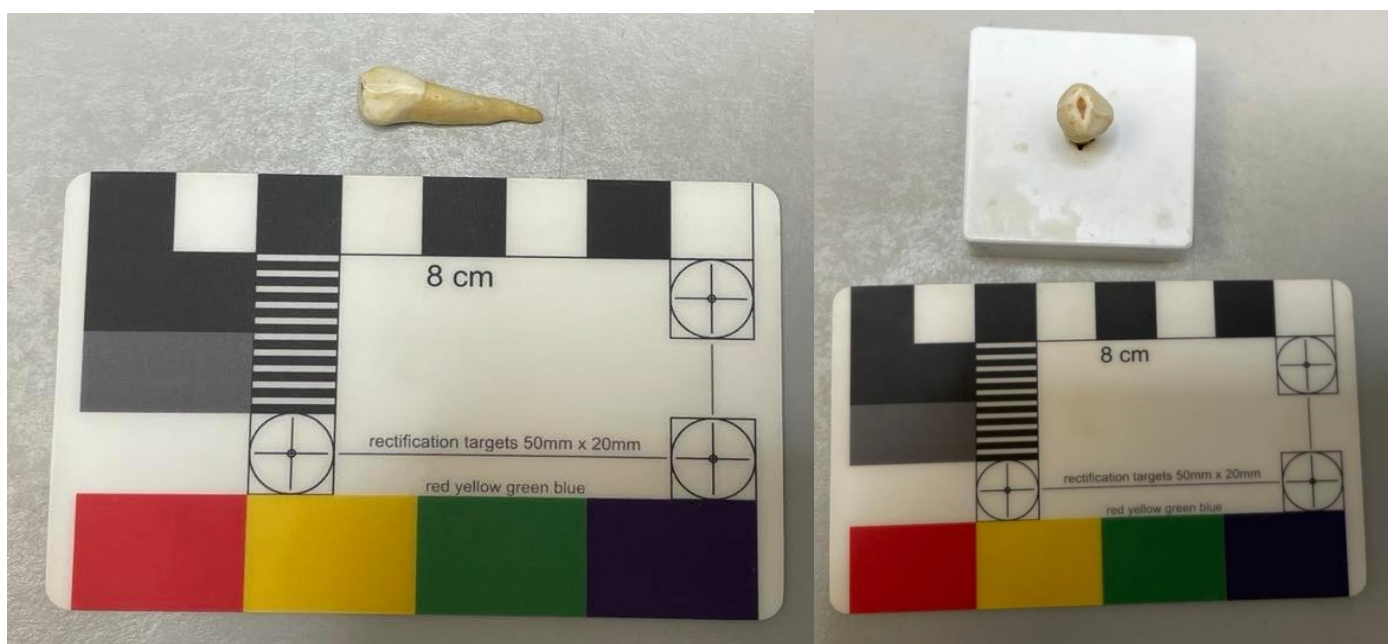


Figure 5: Record photographs for the RC- demonstrating length and overall appearance (lateral view: left) and the wear and exposed dentine on the crown (occlusal view: right) (Photos taken by author 2021)

The RM³ was chosen for analysis as this tooth, which develops between the ages of 8.5-23.5 ± 0.5 years (AlQahtani 2009), was in the final stages of formation at the time of death, with the root length complete but the apex not yet fully closed (Moorees 1963). This incomplete development was well-suited for incremental dentine analysis, as the isotope ratios measured in the final root increments will be representative of tissue being incorporated into the tooth's structure during the last few weeks and months of life (Beaumont *et al.* 2013: 278), therefore potentially allowing interpretation of dietary or physiological changes around the time of death. Conversely, the formation of the RC⁻ begins around 7.5 months old ± 1.5 months and developmental completion is reached by 14.5 years of age ± 0.5 years (AlQahtani 2009; Beaumont and Montgomery 2015). Therefore, as this canine forms at an earlier age than the RM³ it was selected to extend the temporal resolution of the incremental dentine profile, which is possible as the developmental ages of the two teeth overlap by around six years meaning that certain increments within both teeth formed at the same time and should in theory have very similar carbon and nitrogen isotope compositions (Beaumont *et al.* 2013: 287-288). Additionally, the RC⁻ was assessed to be in wear stage three (Smith 1984) as exposed dentine was visible on the incisal surface, which may potentially mean that dentine from the tip of the canine's coronal region has been lost or exposed to diagenetic alteration and may impact results of the trace element analysis. These potential limitations will be discussed further in Chapter 6. Nevertheless, this particular tooth was also chosen to complement and expand the Beaker People Project which sampled few canines (Jay and Richards 2019: 307), thus developing a better understanding of the potential benefits and limitations of using this type of tooth in isotopic studies. The purposeful selection of this particular tooth also prevented unnecessary destruction as the RC⁻ was already loose in the maxilla and required less force to remove in comparison to other teeth.

4.3 Oxygen Isotope Analysis

Enamel samples from both teeth were taken for oxygen isotope analysis to investigate potential mobility between the individual's childhood place of residence and their eventual burial in modern-day Oakslaw. A minimum of 16mg of enamel was required for duplicate sampling, with 19mg taken for the RC⁻ and 20mg for the RM³. The teeth were sampled individually to prevent cross-contamination and sample mixing, with all equipment sterilised before and after sampling. The teeth were first cleaned using a diamond burr in a foot-pedal controlled dental handpiece on a low setting to remove surface contaminants from the burial

or laboratory environment, then after sterilising the bur, the speed setting was increased and the enamel was powdered and collected in labelled microtubes before being sent to Iso-Analytical for analysis. Here, the samples were flushed with helium and combined with phosphoric acid to convert the carbonate in the enamel powder to CO₂ gas required for analysis by Continuous Flow-Isotope Ratio Mass Spectrometry (CF-IRMS). The chromatographic peak produced by resolving the CO₂ using a packed column gas chromatograph was then exposed to the ion source of the Europa Scientific 20-20 IRMS to be ionised and accelerated. From this, gas species of differing masses were separated using electromagnets to manipulate the ion stream, with $\delta^{18}\text{O}$ values obtained by measuring the CO₂ at mass-to-charge ratios 44, 45, and 46 (Iso-Analytical 2021). Iso-Analytical used their own reference materials IA-R022 and IA-R066 calibrated respectively against standard materials NBS-18 and NBS-19; and NBS-18 and IAEA-CO-1 used for inter-laboratory comparison, as well as the reference material Y-02 which has mean values for past analyses conducted in their laboratory. The analytical uncertainties for IA-R066, IA-R022, and Y-02 were $\pm 0.07\text{‰}$ (1σ), $\pm 0.11\text{‰}$ (1σ), and $\pm 0.01\text{‰}$ (1σ), respectively, with $\pm 0.2\text{‰}$ at 1σ or better being the standard accepted uncertainty for routine error. Iso-Analytical could not provide the analytical uncertainty for NBS-18 as the second replicate reaction failed, although the first replicate value of -23.20‰ for $\delta^{18}\text{O}_{\text{VPDB}}$ was used as the accepted value.

The resulting values of $\delta^{18}\text{O}$ for the duplicate samples of both teeth and their mean values are presented in Chapter 5 and are reported relative to the Vienna PeeDee Belemnite (VPDB) standard scale. However, these carbonate $\delta^{18}\text{O}_{\text{VPDB}}$ values are not representative of drinking water or precipitation values, and thus required conversion to the Vienna Standard Mean Ocean Water (VSMOW) scale and further conversion to phosphate $\delta^{18}\text{O}$ values to be compared with oxygen isotope ratios measured in the Beaker People Project (Parker Pearson *et al.* 2019) and existing datasets and contour maps for oxygen isotope variation in modern drinking water sources across Britain (Darling *et al.* 2003). The equation [$\delta^{18}\text{O}_{\text{VSMOW}} = 1.03091 * \delta^{18}\text{O}_{\text{VPDB}} + 30.91$] (Coplen 1988) was first used to convert the carbonate oxygen values ($\delta^{18}\text{O}_{\text{c}}$) from the VPDB scale to the VSMOW scale. From this, $\delta^{18}\text{O}$ values for drinking water ($\delta^{18}\text{O}_{\text{dw}}$) in relation to the VSMOW scale were calculated following an equation from Chenery *et al.* (2012), which combines their own equation for the conversion of the carbonate oxygen values to phosphate oxygen values ($\delta^{18}\text{O}_{\text{p}}$), and Daux and colleagues' (2008) equation 6 for drinking water. This ultimately provided the equation: [$\delta^{18}\text{O}_{\text{dw}} = 1.590 * \delta^{18}\text{O}_{\text{c}} - 48.634$]. The $\delta^{18}\text{O}_{\text{p}}$ values relative to the VSMOW scale were also

calculated independently from this using the equation [$\delta^{18}\text{O}_p = 1.0322 * \delta^{18}\text{O}_c - 9.6849$] (Chenery *et al.* 2012), to maximise the amount of pre-existing oxygen isotope data these results could be compared with for contextualisation and to facilitate the formation of credible interpretations. It should be noted, however, that the use of these conversion equations introduces a much larger error to the data than the original analytical uncertainties from Iso-Analytical's analysis, with the derived $\delta^{18}\text{O}_{dw}$ values in particular having an analytical uncertainty of $\pm 1\text{‰}$ at 2σ (Chenery *et al.* 2012).

4.4 Strontium Isotope Analysis

Enamel was also sampled from both teeth for strontium isotope analysis using a sterilised diamond saw in the dental handpiece to extract an enamel chip of at least 10mg. A chip measuring 13mg was collected for the RM³, and a 24mg chip was sampled from the RC⁻, with care being taken to remove dentine from the enamel using the diamond bur before the chips were stored in separate labelled microtubes. These samples were prepared and analysed in Durham University's ultra-clean Arthur Holmes Isotope Geology Laboratory (AHIGL) following column chemistry methods of Font *et al.* (2008). 3M HNO₃ was used to digest the samples at 100°C on a hotplate, before they were transferred to columns cleaned with ultra-pure water (MQ H₂O) and 6M hydrochloric acid (HCl) containing preconditioned Eichrom strontium-specific resin. 400µL of MQ H₂O was added to the resin to elute a purified strontium fraction, which was then acidified using 15.5M HNO₃ to yield a 3% HNO₃ solution. Before the purified strontium samples were introduced to an ESI PFA-50 nebuliser coupled to a Glass Expansion Cinnabar micro-cyclonic spraychamber to be aspirated, their ⁸⁶Sr beam sizes were individually tested to determine dilution factors that ensured the samples yielded an approximate beam size of approximately 25V ⁸⁸Sr to match the intensity of the international isotope reference standard NBS987. A static multi-collection routine was used to measure strontium isotopes, with each measurement involving a single block of 50 cycles where each cycle had a 4s integration time. To correct instrumental mass bias an ⁸⁸Sr/⁸⁶Sr ratio of 8.375209 and an exponential law were used, and isobaric interferences from Rb and Kr on ⁸⁷Sr and ⁸⁶Sr were corrected using ⁸⁵Rb and ⁸³Kr as monitor masses, although the latter corrections were insignificant. The ⁸⁵Rb intensity was 0.3mV with an ⁸⁵Rb/⁸⁸Sr ratio of 0.013 (0.012), and ⁸³Kr was between 0.06-0.16mV for all samples. NBS987 was run regularly throughout the sample analysis session, and gave a mean ⁸⁷Sr/⁸⁶Sr ratio and reproducibility of 0.710266 ± 0.000013 to 2σ (n = 12). Based on internal precision of

individual analysis and the reference material's analytical reproducibility, 0.000013 (2σ) was considered to be the maximum error, with all samples' strontium isotope data being normalised to an 'accepted' value of 0.71024 for NBS987.

4.5 Trace Element Analysis

Additional enamel chips were taken for trace element analysis, with 19mg collected from the RM³ and 12.3mg from the RC⁻, using the same sampling technique described for strontium isotope analysis. The labelled microtubes containing the enamel samples were also sent to the Arthur Holmes Isotope Geology Laboratory where 1mL of 3M HNO₃ was used to digest the samples. Following digestion, an aliquot of each sample was diluted to provide around 5g per 1mL (0.5 mg mL⁻¹) to ensure the total dissolved solids remained at a sufficiently low level to reduce matrix suppression effects within the analytical instruments. A Thermo Scientific X-Series was used to analyse the diluted samples via Inductively Coupled Plasma Mass Spectrometry (ICP-MS), with an external calibration used for the minor elements. To maximise instrument sensitivity and reduce potential spectroscopic interferences, the machine was optimised before use. The trace element analysis results are presented in Chapter 5 and are reported in parts per million (ppm), equivalent to ng mg⁻¹.

4.6 Incremental Dentine Analysis of Carbon and Nitrogen Isotopes

Whilst the oxygen and strontium isotope and trace element composition of the inorganic mineral components within enamel can be used to infer the possible lifetime movements of this Bronze Age individual, carbon and nitrogen isotope ratios measured in organic collagen from dentine within the same teeth can be used to reconstruct diet (Beaumont *et al.* 2013). Bulk collagen samples from this non-remodelling tissue were previously used alongside those extracted from bones to provide carbon and nitrogen isotope values representing an average for the tissues' formation periods. Now, thanks to developments in analytical technology and equipment quality, primary dentine which forms in increments at a known rate can be accurately sampled and isotopically analysed to measure carbon and nitrogen ratios within each increment, thus providing multiple short-term time-constrained averages that can be combined to develop an incremental dentine profile for individual teeth to inform interpretations about dietary sources and changes at a significantly higher temporal resolution than previously possible (Beaumont *et al.* 2014: 212-213). This method was used here for the

RM³ and RC⁻ to construct an incremental dentine profile for this individual covering the ages 7.5 months to around the time of death between 18-25 years of age thanks to the canine's early developing age, the third molar's incomplete development, and the roughly six-year overlap within the formation periods of the two teeth.

4.6.1 Sample Preparation and Collagen Extraction

Dentine increments were obtained for isotope analysis following method two outlined by Beaumont *et al.* (2013), which required tooth demineralisation before increments were sectioned. After all the required enamel samples were collected, the remaining enamel was removed from the teeth using the dental handpiece fitted with a diamond saw, with the enamel-dentine junction (EDJ) kept intact. By this point, both teeth had also been vertically bisected using the saw to retain half of each tooth with its enamel and dentine intact for future analyses and restrict overall sample destruction, with the halves not used for sampling labelled and stored appropriately before being returned to the rest of the skeletal remains (Mays 2013: 10). Once the enamel was removed, care was taken to limit the effect of minor tissues such as secondary dentine on measured collagen isotope ratios by burring the pulp cavity, although the impacts of these tissues is believed to be minimal (Beaumont *et al.* 2013: 280). The tooth samples were then demineralised via a series of acid changes using 0.5M HCl, during which they were stored in a fridge at approximately 4°C. This process was lengthy, with the RM³ taking longer to demineralise than the RC⁻ due to its larger weight and thickness, and both teeth taking around one month for demineralisation to be complete.

Once this occurred, the demineralised teeth were then rinsed three times with deionised water to remove remaining HCl for sectioning, with both teeth assessed to have retained their original length and shape after demineralisation as a result of their good state of preservation. Transverse dentine samples were taken using a sterilised scalpel and tweezers and were cut at 1mm intervals along the length of each tooth from crown to root, with a sterilised metal ruler used to measure increments. Sixteen increment samples were collected for the 16mm-long RM³, and due to small inconsistencies resulting from human error when measuring, 27 increments were collected for the 24mm-long RC⁻, with all increments stored in microtubes appropriately labelled to keep track of each tooth's increment sample order. As each increment develops over time and the isotope ratios measured for each one will therefore represent an average value for its formation period, the age represented by each increment was determined by dividing each tooth's overall developmental age range deduced

from AlQahtani (2009) by the number of increments sampled from it (see Table 2 and 3). Thus, as the RM³ develops between 8.5-23.5 years old for a total growth period of 15 years, each increment's formation lasts 0.9375 years. As for the RC⁻ which forms between 7.5 months-15 years old for a total development period of 15.125 years, each increment increases in age by 0.5602 years. The midpoint of each increment's development age range was calculated to correspond the average carbon and nitrogen isotope ratios of each increment to the age they represent (Beaumont *et al.* 2013: 284-285).

Table 2: The age ranges represented by the 16 molar (RM³) increments are presented here with their midpoints (1dp). These increments increased in age by 0.9375 years between the ages 8.5-23.5 years. However, the age-at-death of this individual is estimated as 18-25 years old and the root apex was incomplete, so the ages given for the later-forming increments are representative of the individuals 'later life' and are based on a fully developed third molar

RM ³ Increment	Increment Age Range (years)	Increment Age Midpoint
1	8.5 - 9.4375	8.9
2	9.4375 - 10.375	9.9
3	10.375 - 11.3125	10.8
4	11.3125 - 12.25	11.8
5	12.25 - 13.1875	12.7
6	13.1875 - 14.125	13.7
7	14.125 - 15.0625	14.6
8	15.0625 - 16	15.5
9	16 - 16.9375	16.5
10	16.9375 - 17.875	17.4
11	17.875 - 18.8125	18.3
12	18.8125 - 19.75	19.3
13	19.75 - 20.6875	20.2
14	20.6875 - 21.625	21.2
15	21.625 - 22.5625	22.1
16	22.5625 - 23.5	23.0

Table 3: The ages represented by the 27 canine (RC-) increments are shown here with their midpoints (rounded to 1 d.p.). The increments increased in age by 0.5602 years from 7.5 months to 15.5 years old. Three pairs of increments were combined producing a total of 24 collagen samples for isotope analysis

RC- Increment	Increment Age Range (years)	Increment Age Midpoint
1 and 2	0.625 – 1.7454	1.2
3	1.7454 – 2.3056	2.0
4	2.3056 – 2.8658	2.6
5	2.8658 – 3.426	3.1
6	3.426 – 3.9862	3.7
7	3.9862 – 4.5464	4.3
8	4.5464 – 5.1066	4.8
9	5.1066 – 5.6668	5.4
10	5.6668 – 6.227	5.9
11	6.227 – 6.7872	6.5
12	6.7872 – 7.3474	7.1
13	7.3474 – 7.9076	7.6
14	7.9076 – 8.4678	8.2
15	8.4678 – 9.028	8.7
16	9.028 – 9.5882	9.3
17	9.5882 – 10.1484	9.9
18	10.1484 – 10.7086	10.4
19	10.7086 – 11.2688	10.9
20	11.2688 – 11.829	11.5
21	11.829 – 12.3892	12.1
22	12.3892 – 12.9494	12.7
23	12.9494 – 13.5096	13.2
24 and 25	13.5096 – 14.63	14.1
26 and 27	14.63 – 15.7504	15.2

Subsequently, the dentine increments were prepared for collagen extraction and isotope analysis using a modified version of the Longin method (Brown *et al.* 1988; O’Connell and Hedges 1999), which involved adding a pH 3 HCl solution to the microtubes

containing the increments and placing them on a heater block at 70°C for 24-48 hours. This process denatured the collagen, with the samples then being centrifuged for five minutes to collect any debris with a higher density than the collagen within a pellet at the bottom of the microtube for removal, which served as an adequate substitute for filtration. Finally, the centrifuged samples were placed in a freezer for at least 24 hours before being freeze dried. The resultant collagen samples were individually weighed after freeze drying was complete, with 2.5mg being the minimum weight required for a sufficient collagen yield to analyse each sample in duplicate (Beaumont *et al.* 2013: 284-285).

4.6.2 Incremental Carbon and Nitrogen Isotope Analysis

Once the incremental samples were obtained from each tooth, aliquots of collagen from each one measuring between 0.3-0.5 mg were weighed into 5x3.5mm tin capsules, with the equipment used being sterilised between each measurement to prevent cross-contamination. Increments 1 and 2; 24 and 25; and 26 and 27 from the RC⁻ had to be combined to provide sufficient collagen to meet the 0.3-0.5mg weight requirement for carbon and nitrogen isotope analysis. No increments from the RM³ needed to be combined. These collagen samples were then measured using a ThermoScientific Delta V Advantage gas-source mass spectrometer and a COSTECH Elemental Analyser in the Stable Isotope Biogeochemistry Laboratory at Durham University's Geochemistry Centre. Internal reference standards (Urea, SPAR, Glycine, and Glutamic acid) and international reference standards (USGS 24, USGS 40, IAEA 600, IAEA N1, and IAEA N2) were run alongside the samples during analysis and were used to calibrate the isotope analysis results which are expressed relative to the Vienna PeeDee Belemnite (VPDB) scale for carbon and the Ambient Inhalable Reservoir (AIR) for nitrogen. The analytical uncertainty was $\pm 0.1\%$ at 1σ for the international standards, and $\pm 0.2\%$ (1σ) for replicate analysis of the samples. Along with the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values, C:N atomic ratios were also obtained to investigate the preservation quality of the collagen (Ambrose 1990), as well as results for the total organic carbon and nitrogen content of each sample.

4.7 Bulk Carbon and Nitrogen Isotope Analysis

As stated above, collagen from bulk bone samples can be used to study past diets by providing isotope ratios of carbon and nitrogen that are averaged over the period of the

bone's growth. Because bone remodels continuously throughout life, the isotope values of carbon and nitrogen measured within the tissue represent an average for the isotopes incorporated from the diet over an individual's lifetime, and do not just correspond to childhood diet like dentine (Loftus and Sealy 2012: 49-501). Hence, whilst bulk bone analysis does not permit the high degree of temporal resolution possible with incremental dentine analysis, by comparing the isotopic composition of bone and dentine changes in diet and even potential movement from an individual's childhood residence may be interpreted if the observed carbon and nitrogen ratios are significantly different between the two tissues (Parker Pearson *et al.* 2016: 625-626). In the Beaker People project, bone taken from the mandible was preferred to provide a compact bulk sample directly associated with the extracted teeth, although bone samples were also taken from other parts of the skull, long bones, and ribs if they were available for study (Jay and Richards 2019: 306-307). Here, a fragment of bone from the individual's radius or ulna was selected (Figure 7) to avoid the need to use destructive sampling methods on the well-preserved skull which was coated in many areas with the fibrous material from the burial environment, thus conserving this skeletal element and its important sexually dimorphic features (Mays 2010) for future analyses and avoiding loss and disturbance of the material. This long bone fragment from the forearm was also chosen to provide a large enough collagen sample for radiocarbon dating, with a portion of the bone being removed from the fragment and bisected to provide two samples around the optimum 400mg weight suitable for successful demineralisation. Both bulk bone samples were cleaned and prepared using the same methods and sterilised equipment as described above, and were subjected to the same demineralisation and collagen extraction techniques as the dentine increments. One bone collagen sample was sent to SUERC to obtain a radiocarbon date for the skeleton, and the other was retained for carbon and nitrogen isotope analysis. The latter collagen sample was measured in duplicate using the same methodology, measuring equipment, and standards as for the incremental dentine samples, with the carbon and nitrogen isotope ratio results also being reported relative to the previously stated scales. Lastly, $\delta^{13}\text{C}_{(\text{VPDB})}$ values were also obtained alongside the $\delta^{18}\text{O}_{(\text{VPDB})}$ values from the carbonate in both teeth's enamel samples during analysis by Iso-Analytical, with the measured carbon isotope composition able to be used as a proxy to infer the individual's diet whilst the enamel of each tooth was forming (Loftus and Sealy 2012). The reference material and standards used to obtain and calibrate these values were the same as previously described for the oxygen isotope analysis (Iso-Analytical 2021), and the results are again reported relative to the VPDB scale.



Figure 7: This bone fragment from one of the forearm bones was selected for isotopic analysis. Two samples were taken for collagen extraction, with one sample being sent off for radiocarbon dating., and the other retained for carbon and nitrogen isotope analysis (Photo taken by author 2021)

5. Results

This chapter presents the results of the osteological profiling of the skeleton recovered from Oakslaw, including a summary of the preservation condition, estimation of age-at-death, biological sex, and stature, as well as a description of the identified pathology and non-metric traits. The results of the stable isotope and trace element analyses will also be discussed here, with a purposeful focus placed on describing these results in a concise, factual manner concentrated on the Oakslaw individual themselves, in preparation for the data to be contextualised and interpreted alongside comparative datasets in the discussion section.

5.1 Osteological Re-assessment Results

5.1.1 Preservation Condition

The completeness of the Oakslaw individual was assessed to be good, with an estimated 60-75% of the skeleton present at the time of analysis. Overall, the degree of fragmentation was estimated to be moderate with variable fragmentation across the skeleton as some of the long bones (right humerus, right femur, and both tibiae) were complete, whilst parts of the cranium and ribs in particular were severely fragmented. The preserved skeletal elements are listed in Appendix II and shown in Figure 8, with this also showing that the pelvis and majority of the vertebrae were lost post-mortem in the burial environment and were not recovered during the rescue excavation. Following McKinley's (2004) grading system, the skeleton found at Oakslaw was designated a grade of 4-5 for overall surface preservation as most of the surviving elements displayed cortical bone loss from their outer surfaces, leading to surface morphology modification but a maintenance of the general profile of the bones. This cortical bone loss was presumed to be due to erosion by root action, especially as the surfaces of the right tibia, left femur, left side of the cranium, and the left ramus of the mandible were obscured by the previously mentioned fibrous root-like material, which made it particularly difficult to assess the surface preservation of these affected skeletal elements. However, it is necessary to acknowledge that the surface preservation was also variable across this skeleton, as the right shoulder (scapula, clavicle, and proximal humerus) could be designated a grade 2-3 as the surfaces of the bones have still been impacted by erosion but their morphology has not been altered to the same extent as other parts of the skeleton (McKinley 2004: 15-16). This variation could be explained by these elements being

positioned lowest in the grave due to the individual being interred on their right side, potentially allowing the right shoulder to be better protected from the intrusive roots by the surrounding soil conditions. Therefore, taking all of these factors into account, the general preservation condition of this skeleton is variable but overall poor, with elements from the appendicular skeleton (excluding the pelvic girdle) seemingly better preserved than bones of the axial skeleton. The full skeletal inventory is recorded in Appendix II.

5.1.2 Age-at-Death, Biological Sex, and Stature Estimation

The Oakslaw individuals' age-at-death was estimated to be between 18-25 years old, in line with Nezirovic and Gamble's previous assessments (Carlton 2018: 4-8). This was concluded based on dental development and wear, as all permanent teeth were present and fully erupted, including the four third molars which indicate an age-at-death at or over the age of 18 due to this tooth's known development and eruption age (AlQahtani 2009; Ubelaker 1979; Haavikko 1970). Minimal wear on the first, second, and third permanent molars supported this estimation, especially as the third molars were assigned to Brothwell's (1981: 71-72) wear stage 1 due to them displaying no enamel wear or dentine exposure, with this wear pattern corresponding to an estimated age-at-death between 17-25 years old. Furthermore, the right clavicle was identified as being in the process of epiphyseal fusion due to the presence of a small flake of fused bone on the



Figure 8: The preserved skeletal elements of the Oakslaw individual laid out in anatomical position (photo by author 2021)

sternal end (Figure 9), which suggested an age-at-death above 17 years old and constrained the upper range of the estimation to 25 years old as this epiphysis is usually fused in most individuals before this age (Jit and Kulkarni 1976; Schaefer 2008), although complete fusion can occur as late as 29 years or older (Schaefer *et al.* 2009: 150). The acromion of the right scapula also appeared not to be fused, although this is potentially due to a pathological condition which will be described below. Because the pelvis was not preserved, assessment of the pubic symphysis morphology (Brooks and Suchey 1990) and auricular surface appearance (Lovejoy *et al.* 1985) was not possible, restricting the amount of evidence available to construct the age-at-death estimation. However, the methods used are still accepted and reliable (Buikstra and Ubelaker 1994), and the age-at-death estimation of 18-25 years old was deemed appropriate to cover the possibilities suggested by the different forms of skeletal evidence, thus placing the Oakslaw individual in late adolescence or early adulthood.



Figure 9: The right clavicle (left) and a close-up of the partially fused sternal epiphysis (right). The flake of fusing bone is visible on the left (photo by author 2021)

Biological sex estimation was also partly in agreement with the earlier categorisation of this skeleton as a male (Carlton 2018) due to the identification of more sexually dimorphic features of the skull displaying typical male traits. However, the decision was made to classify the individual as a probable male as some features displayed morphological traits more commonly seen in females or were indeterminate (Buikstra and Ubelaker 1994). For instance, the squared mental eminence of the anterior mandible, the rounded, blunt

supraorbital margin and orbital rims, the square orbits and slight forehead slope in the cranium are suggestive of a probable male sex determination, whilst the lack of a well-defined nuchal crest and supra-mastoid crest are more ambiguous or feminine characteristics (White and Folkens 2005; Buikstra and Ubelaker 1994; Brothwell 1981). Additionally, measurements of the right scapula glenoid width, humeral head width of both humeri, and the distal epiphysis width of the right femur (Appendix II) all fall within the range expected for females, although this method of sex determination may not be reliable for this skeleton due to the poor preservation and loss of cortical bone, as well as the fibrous material coverage inhibiting additional measurement taking, and is therefore generally viewed as less credible than assessment of morphological features (Mays 2010; White and Folkens 2005). Despite this, if the Oakslaw individual was in fact a male, it is possible that these female and indeterminate skeletal features may be explained by the skeleton's young age and possible incomplete skeletal maturity, or the extent of natural individual variation in the skull and its sexually dimorphic features seen within and between populations as well as males and females (White *et al.* 2011; White and Folkens 2005; Buikstra and Ubelaker 1994). Once again, as the pelvis was not preserved, the reliability of the sex determination was limited, but assigning biological sex on the basis of the skull alone has been shown to have an accuracy of 80-90% (White *et al.* 2011), so is more than appropriate to categorise this individual. Nevertheless, the Oakslaw individual will continue to be addressed in this work without using sex or gender-specific pronouns and terminology for continuity and to reflect the possibility of an inaccurate biological sex estimation.

Lastly, stature was estimated by measuring the length of the intact long bones, which included the right humerus (34.1cm), the right femur (43.3cm), and the left tibia (37.3cm). These values were very close to the measurements previously taken by Gamble (in Carlton 2018: 8), who determined the right humerus to be 34cm, the right femur to be 44.8cm, and the left tibia to be 37.7cm in length, thus suggesting these results are reproduceable and reliable. The femoral shaft length measurement was used to calculate the Oakslaw individual's estimated stature using Trotter's equation for white males: $[(2.38 * \text{Femur Length}) + 61.41]$, with this long bone from the leg being used as it contributes to an individual's height so is well correlated with stature (Mays 2016). This equation generated an estimated stature of 164.46cm (± 3.27 cm), which is just outside of Gamble's estimation of 169.47cm (± 3.94 cm) at a 1σ range (Carlton 2018: 8), although this small discrepancy may be due to further post-mortem damage and loss of cortical bone during handling or in storage in the

years since the skeleton was initially investigated in 2017. These estimations of age-at-death, biological sex, and stature were ultimately all in accordance with the previous osteological assessments, therefore confirming a reliable biological identity for this individual.

5.1.3 Pathology and Non-Metric Traits

According to the initial report detailing the finding of the burial at Oakslaw, an assessment of the skeleton concluded that no significant pathologies or traumatic lesions could be identified (Carlton 2018: 4), and this is mostly in agreement with the findings here. The only potential pathological anomaly within the post-cranial skeleton found during the osteological re-assessment was in the right scapula where the tip of the acromion process was identified as absent. The surviving portion of the bone had a porous surface and a linear edge at right angles, with traces of the original bone surface present under magnification despite extensive post-mortem damage. This could possibly represent an unfused acromial epiphysis which usually fuses by 20-25 years old but does not always complete fusion in all individuals (Schaefer *et al.* 2009: 159-164), or could be an example of os acromiale where one or more of the ossification centres of the acromion fails to fuse and remains separate (Hunt and Bullen 2007). The acromion process articulates with the distal end of the clavicle and has attachment points for the deltoideus muscle and trapezius muscle, with the latter involved in scapular rotation (White and Folkens 2005). This is important to note, as os acromiale has been associated with muscle tendon impingement in the shoulder and rotator cuff mobility issues (Hunt and Bullen 2007). However, this anomaly has also previously been linked to activity such as archery in other archaeological samples (see for example: Friend 2012; Stirland 1992). Unfortunately, the acromion process of the left scapula was not preserved, so was not available for comparison.

As for dental pathology, all of the teeth were present at the time of analysis, but the left maxillary premolars and molars were unobservable as they were obscured by the fibrous material. Calculus was identified on all observable teeth ($n = 27$) and ranged in severity from flecks to slight deposits (Brothwell 1981). This correlates to 84% of the individual's teeth being affected by calculus, with many different lifestyle factors such as diet, health, and oral hygiene possibly influencing this high occurrence (Roberts and Manchester 2010). Periodontal disease was absent in the alveolar bone of the upper right section of the maxilla, and lower right section of the mandible, but was unobservable in the upper left maxilla. However, in the alveolar bone of the lower left mandible, periodontal disease was identified

with a slight severity, although it is difficult to discern whether this damage instead occurred post-mortem due to the poor preservation condition of the bone surface. Therefore, overall the preserved skeletal remains of this individual display no evidence of significant pathologies or trauma that could be used to infer a potential cause of death or possible co-morbidity factors influencing the demise of this young person.

5.2 Oxygen and Strontium Isotope Analysis Results

The strontium and oxygen isotope ratios measured for the RC⁻ and RM³ enamel samples taken from the Oakslaw individual are presented in Table 4. The results of these two isotope analyses are presented together within this table as they will be combined and contextualised in detail within the following chapter to infer mobility and the individual's locality in relation to Rock, but will be discussed separately within this section to examine the potential origins they suggest when considered independently.

Table 4: The strontium and oxygen isotope analysis results for the two teeth studied. The converted oxygen isotope ratios for drinking water and phosphate are also shown

Sample	Sample number	⁸⁷ Sr/ ⁸⁶ Sr	1σ	δ ¹⁸ O _{VPDB} (‰)	Mean δ ¹⁸ O _{VPDB} (‰)	1σ	δ ¹⁸ O _{C(VSMOW)} (‰)	δ ¹⁸ O _{dw(VSMOW)} (‰)	1σ	δ ¹⁸ O _{p(VSMOW)} (‰)	1σ
RC ⁻	9541	0.7114	0.000009	-4.69	-4.7	0.01	26.06	-7.19	1.00	17.22	0.28
				-4.71							
RM ³	9542	0.7106	0.000009	-5.43	-5.19	0.34	25.56	-7.99	1.00	16.70	0.28
				-4.94							

5.2.1 Oxygen Isotope Analysis Results

The powdered enamel samples taken from each tooth for oxygen isotope analysis were run in duplicate by Iso-Analytical, and yielded δ¹⁸O_{VPDB} values of -4.69‰ and -4.71‰ (mean -4.7‰) for the RC⁻, and -5.43‰ and -4.94‰ (mean -5.19‰) for the RM³. These carbonate oxygen values were converted from the VPDB scale to the VSMOW scale using the equations outlined in the methodology, and were further converted to phosphate oxygen values (δ¹⁸O_p) for comparison with the results within the Beaker People Project database (Parker Pearson *et al.* 2019), and drinking water values (δ¹⁸O_{dw}) to be related to oxygen

isotope contour maps of Britain (Darling *et al.* 2003; BGS 2004, 2022a). The converted values are also presented in Table 4. The range of the $\delta^{18}\text{O}_\text{p}$ values between the individual's two teeth was 0.52‰, although this difference does not appear to be significant, as when the analytical uncertainties are taken into account the RC^- and RM^3 $\delta^{18}\text{O}_\text{p}$ values overlap within a 1σ range. Nevertheless, the oxygen isotope ratios for both teeth fall within the expected range of $\delta^{18}\text{O}_\text{p}$ values for human enamel samples from British archaeological sites, which is suggested to be between 16.3‰ and 19.1‰ (Evans *et al.* 2012). Additionally, the $\delta^{18}\text{O}_\text{dw}$ values for the RC^- and RM^3 lie within Darling and colleagues' (2003) suggested range of -9‰ to -4.5‰ for oxygen isotope ratios of modern UK groundwater (Figure 10). Together, this implies that the Oakslaw individual's oxygen isotope ratios are consistent with an upbringing and life spent in Britain, although it must be noted that this does not exclude a potential non-UK origin as similar oxygen isotope ratios can also be found across parts of Europe (Figure 11).

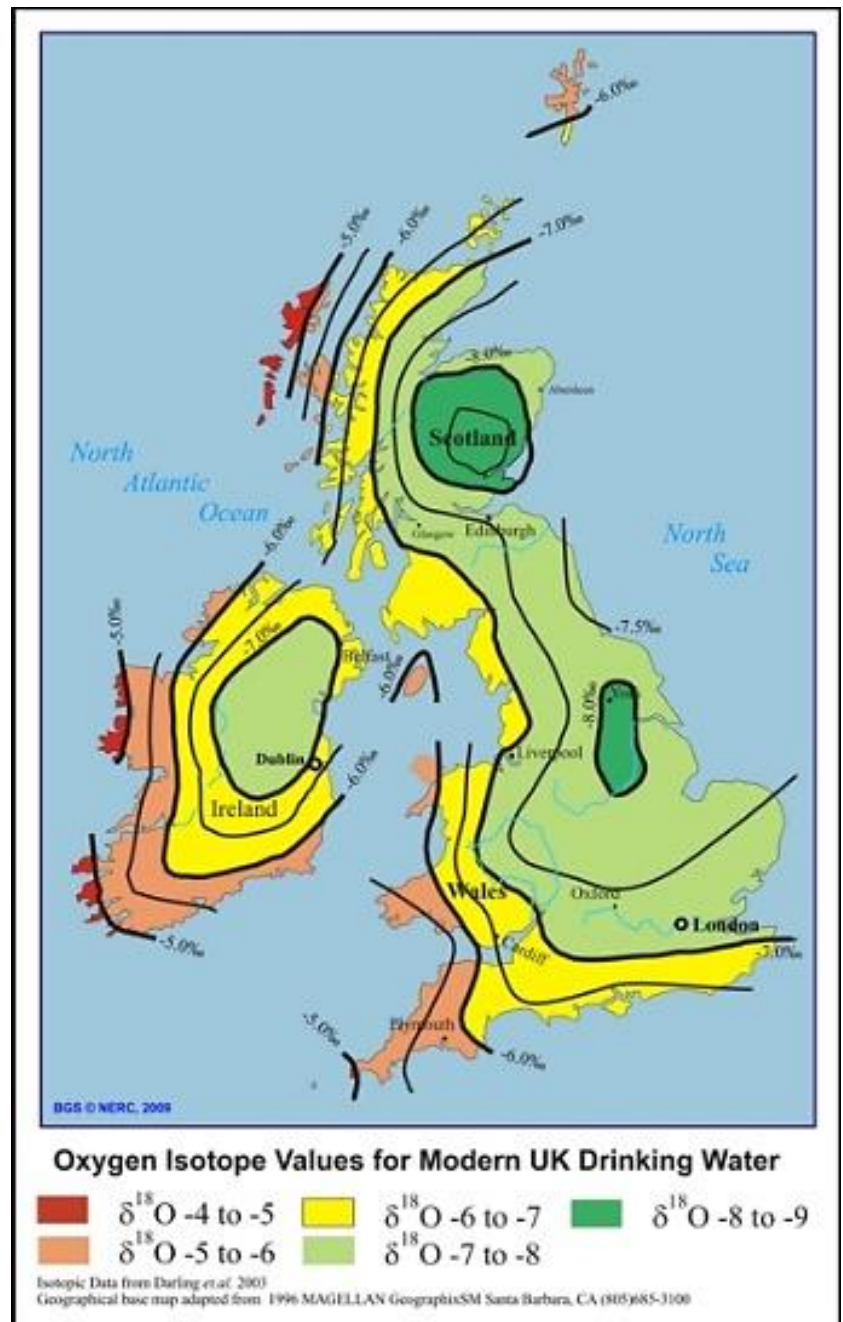


Figure 10: This map shows the variation of oxygen isotope ratios observed in modern drinking water across the UK (Darling *et al.* 2003)

Oxygen Isotopes Values for Modern European Drinking Water

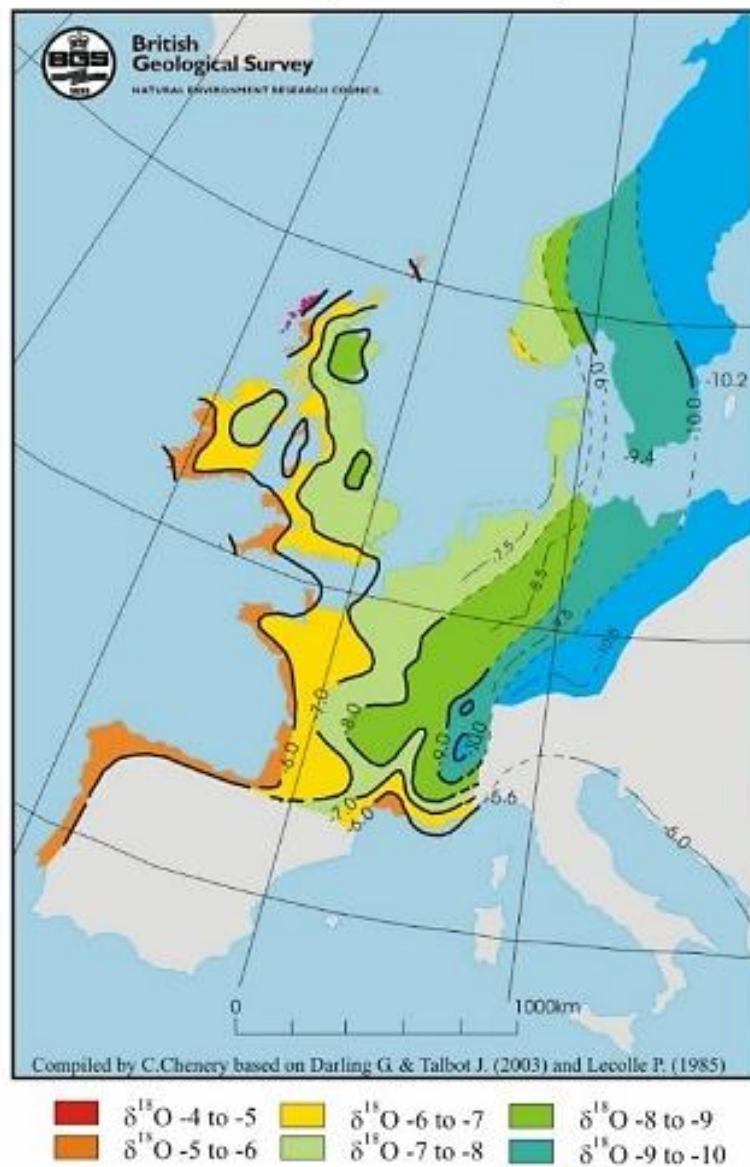


Figure 11: This map shows the variation of oxygen isotope ratios for drinking water across Europe, with some areas of the UK producing similar ratios to parts of Europe (BGS 2004)

To further refine the potential residential origins suggested by the oxygen isotope ratios measured in the teeth it is important to consider where within Britain the results are consistent with, as well as the areas that can be excluded as a potential place of origin. Both the RC^- and RM^3 's $\delta^{18}\text{O}_\text{p}$ values (17.22‰ and 16.70‰, respectively), fit well within Evans and colleagues' (2012) proposed 2σ range of 15.9‰ to 18.5‰ (mean 17.2‰ $\pm$ 1.3‰) for an origin on the eastern side of Britain where lower $\delta^{18}\text{O}_\text{p}$ values are expected compared to the west due to lower levels of rainfall. Moreover, the lower $\delta^{18}\text{O}_\text{p}$ value for the RM^3 is completely out of the range expected for western Britain (17.2‰ to 19.2‰ at 2σ), implying that the Oakslaw individual likely did not reside on the west coast of Britain during the formation of this tooth until their death in late adolescence. The same can be suggested for

the RC⁻ although with slightly less confidence, as although the tooth's $\delta^{18}\text{O}_p$ value is within the range for western Britain at 2σ , it represents the minimum value within this range and is excluded from the 1σ range (17.7‰ to 18.7‰), whereas it is still within the 1σ range (16.55‰ to 17.85‰) for eastern Britain (Evans *et al.* 2012). A more easterly provenance for both teeth is also supported by the British Geological Survey's (BGS) biosphere isotope domain map for Great Britain, which is a GIS database collating multiple published isotope datasets to show their distribution across Britain, that allows users to input isotope ratios measured in their samples and identify the areas that are most compatible with their results (Evans *et al.* 2018). When the $\delta^{18}\text{O}_p$ values of the two teeth are entered in as a sample query they both produce the same distribution map (Figure 12) which excludes the west coast and much of the south coast, where higher oxygen values are expected due to higher levels of rainfall (Evans *et al.* 2012: 759), as potential places of residential origin. Thus, this ultimately advocates that this young individual found at Oakslaw did not live on the western side of Britain during their childhood and later life, with a residential origin closer to the east coast with low levels of rainfall being deemed more probable by the oxygen isotope ratios of both of the studied teeth. This evidence will be expanded upon further in Chapter 6, where this data will be combined with results of the strontium isotope analysis and comparative datasets to infer whether this person was likely local to their burial place in Rock.

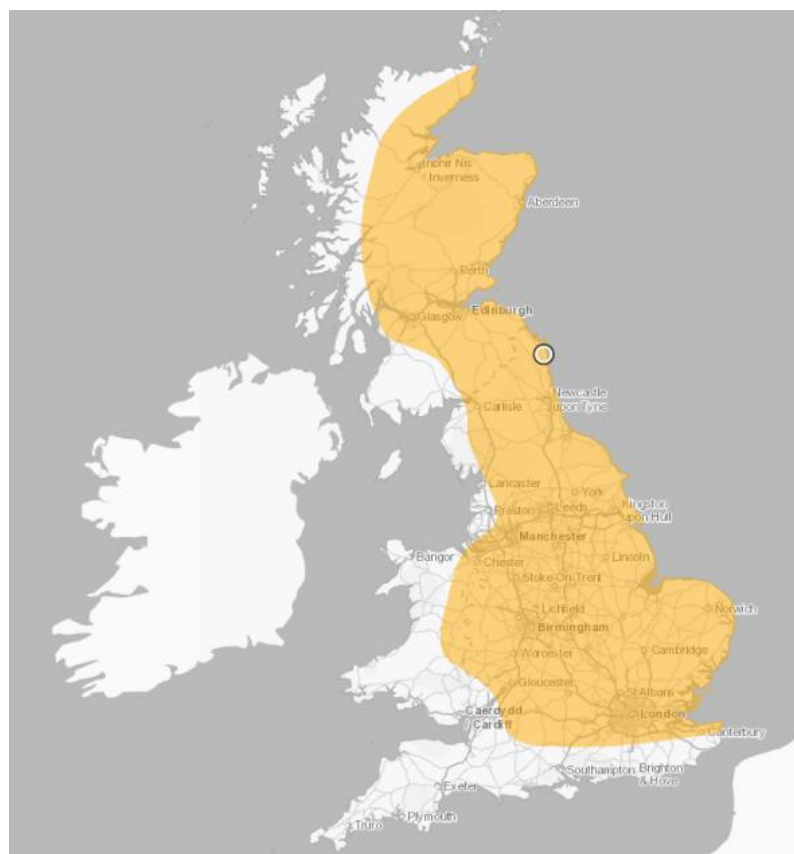


Figure 12: The results of the sample query on the BGS isotope domain map for the oxygen isotope ratios for both teeth. The area of the map highlighted in yellow indicates areas consistent with the oxygen isotope ratios. The circle is Rock's location (BGS 2022a)

5.2.2 Strontium Isotope Analysis Results

As seen in Table 4, the $^{87}\text{Sr}/^{86}\text{Sr}$ ratios obtained for the RC^- and RM^3 were 0.7114 and 0.7106, respectively, with a difference of 0.0008 between the measurements for the two teeth. This difference suggests the two strontium ratios are significantly different, as 0.0008 is much greater than the analytical uncertainties associated with the ratios at both a 1σ (± 0.000009) and 2σ range (± 0.000018). Therefore, the earlier developing RC^- which is used to infer the Oaksław individual's residential origins during childhood, has a higher strontium isotope ratio than the later forming RM^3 used to provenance the individual's possible locality in later life and around the time of death. However, it is important to acknowledge that groups of humans or animals living within the same restricted area their whole lives may still exhibit variation between their measured strontium isotope ratios due to many different factors (Towers 2013), which will be discussed further in the following chapter. Like the oxygen isotope ratios, the $^{87}\text{Sr}/^{86}\text{Sr}$ ratios for both the RC^- and RM^3 fall within the variation expected for Britain, which Evans and colleagues (2012) estimated to range from 0.7078 to 0.7142 for England and Wales, and to a higher value of 0.7165 for Scotland by collating empirical measured data from archaeological publications. Once again however, this does not completely rule out a potential origin outside of Britain as many parts of Europe can produce similar strontium isotope ratios to many regions in Britain (Figure 13) due to their shared underlying lithologies (Bataille *et al.* 2018).

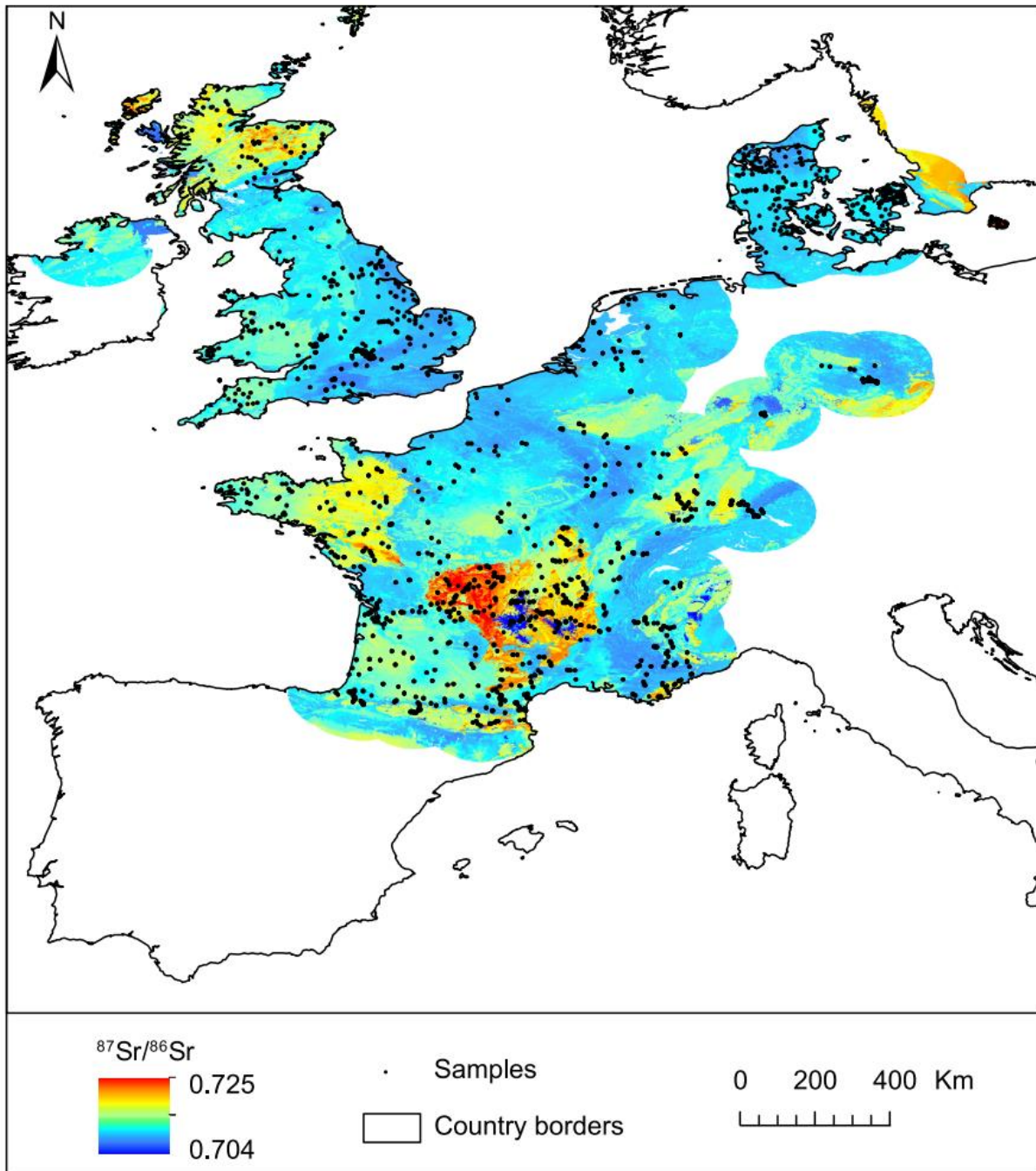


Figure 13: This map demonstrates the distribution of biosphere strontium isotope ratios across Europe, with many regions producing very similar values (Bataille *et al.* 2018: fig 9)

Despite this, when considering the type of lithologies these values are consistent and inconsistent with in the context of Britain (Figure 14), both of the teeth's ratios would for example be too high for the homogeneous Cretaceous Chalk bedrock covering much of south and south-east England and the young Tertiary Volcanic terrain of Scotland, whilst alternatively being too low for the Metamorphic and granite lithologies of Scotland, the

Ordovician bedrock of central Wales and the Carboniferous Grits and Devonian lithologies of south-west England (Evans *et al.* 2010; 2012; BGS 2022b). Instead, when the higher strontium isotope ratio for the RC⁻ is entered into the BGS database, it appears to be most consistent with Sedimentary bedrock formed in the Carboniferous and Silurian periods (Figure 15) found across parts of north-east England, central England, Wales, south-west England, western Scotland, and the Scottish borders (BGS 2022a). As for the RM³'s lower strontium isotope ratio, the distribution of possible origins is slightly more restricted than for the RC⁻ (Figure 16), with Sedimentary and Igneous bedrocks formed during the Devonian and Silurian periods and found in the Scottish border region, the Cheviot Hills in Northumberland, parts of central England, Wales, south-east England, and south England identified as being consistent with this value (BGS 2022a). These provenance possibilities will be further contextualised in relation to Oakslaw and scrutinised within the discussion chapter as the nature of the BGS dataset means that some suggested localities may have been identified due to extrapolated data ranges, rather than being based on empirical measurements, since not all areas of Britain have equal coverage in the published sources used to construct the map (Evans *et al.* 2018: 9-10). Finally, it is also worth noting that both of the strontium isotope ratios measured for this individual are above the value for seawater (0.7092) from which rainwater is sourced (McArthur *et al.* 2001).

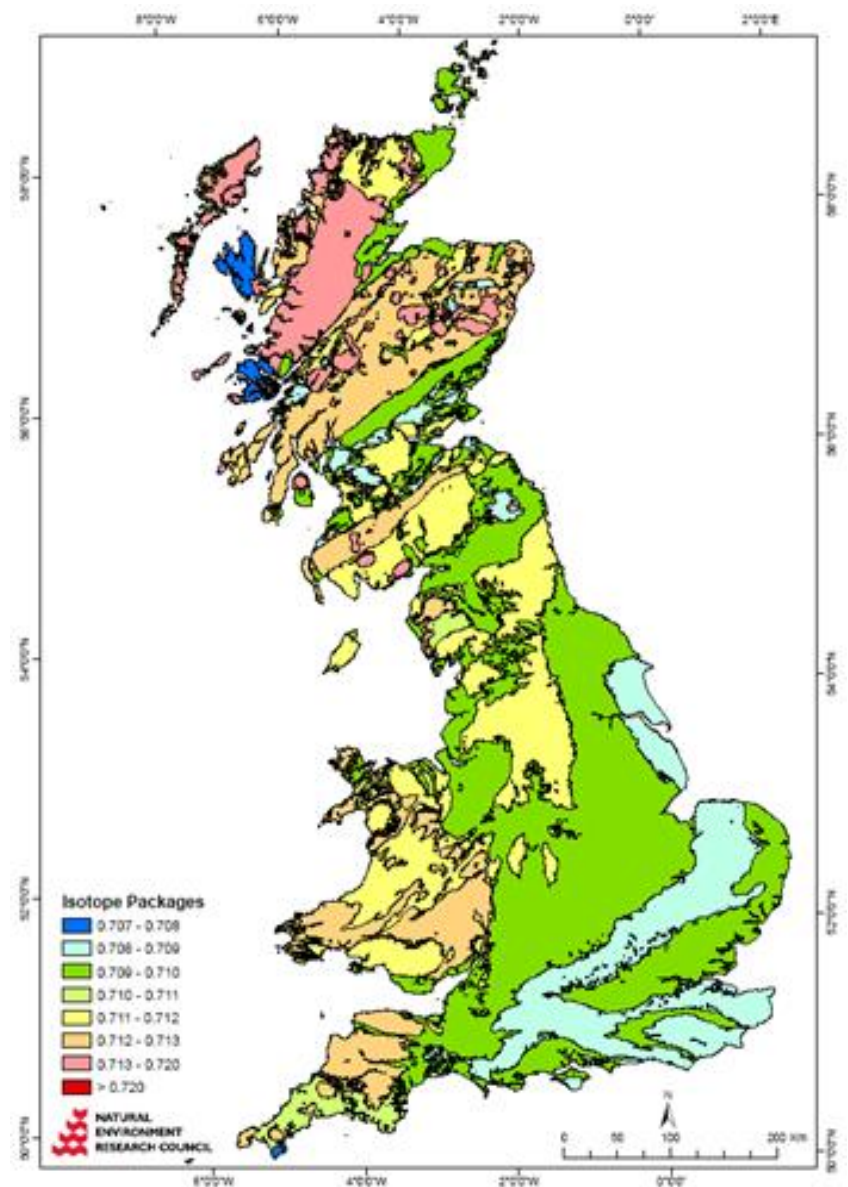


Figure 14: The strontium isotope ratio variation expected across Britain due to different underlying geologies. According to this extrapolated map, strontium values consistent with Rock should fall between 0.709-0.710 (Evans *et al.* 2010)

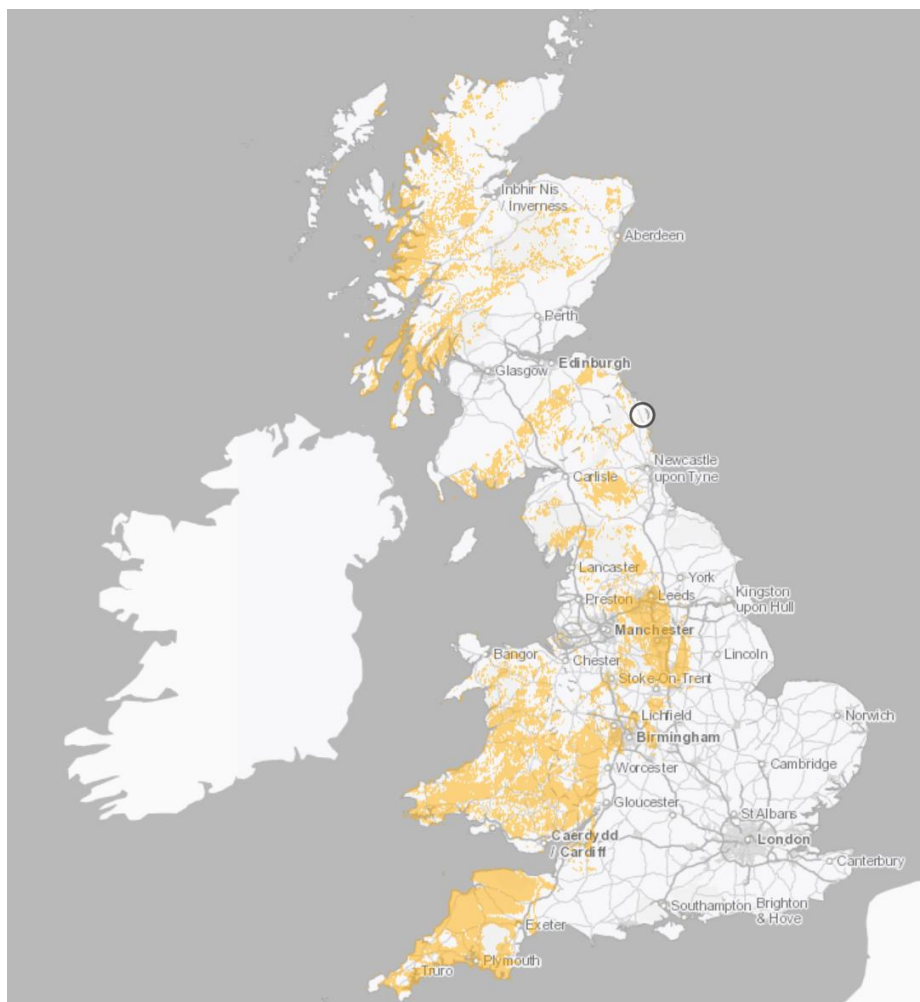


Figure 15: The areas of Britain identified by the BGS isotope domain map to be consistent with the strontium isotope ratios of the RC- (BGS 2022a)

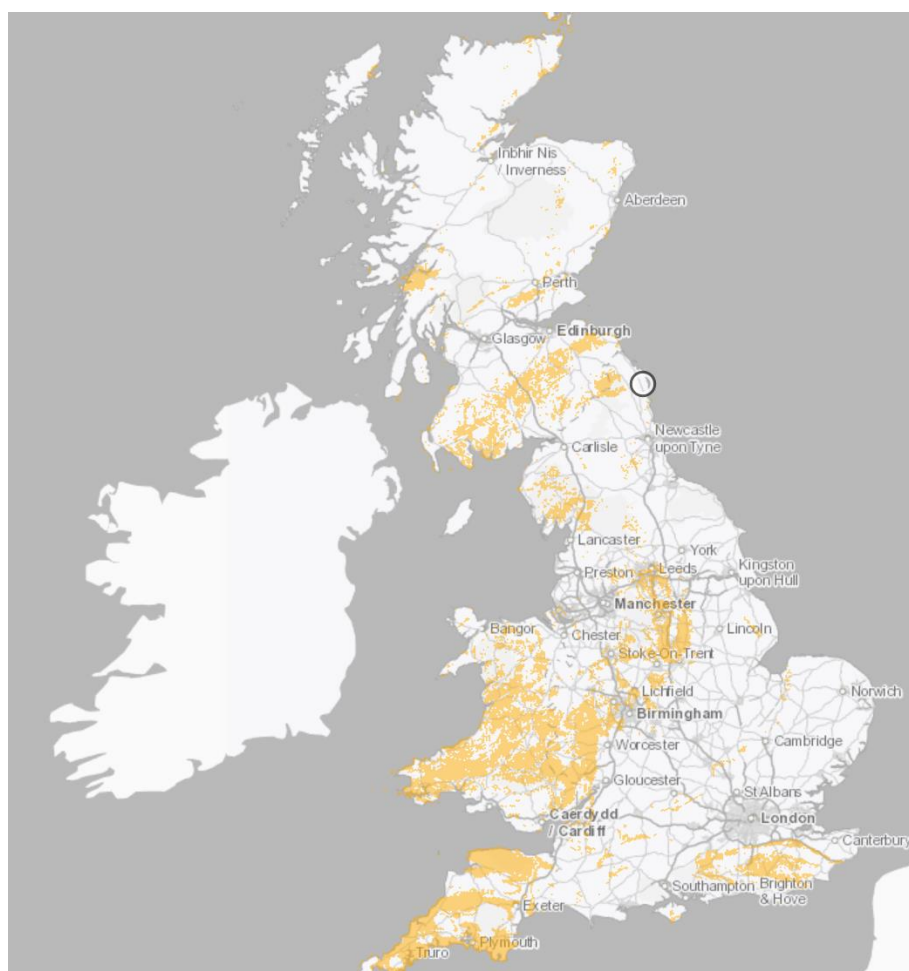


Figure 15: The areas of Britain identified by the BGS isotope domain map to be consistent with the strontium isotope ratios of the RM³ (BGS 2022a)

5.3 Trace Element Analysis Results

Enamel samples taken from the RC⁻ and RM³ underwent trace element analysis and yielded concentration measurements for strontium, lead, magnesium, copper, zinc, and barium. Measurements were obtained for different isotopes of each element, with the most abundant isotope (highest value) being chosen to represent the element's concentration. However, only the strontium and lead concentrations were deemed most suitable and useful to be interpreted further in order to contextualise the Oaksław individual's life history, due to the existing use of these particular elements within archaeological literature and availability of comparative data in comparison to the other elements (see for example: Montgomery *et al.* 2010; Montgomery 2010; Simpson *et al.* 2021: 9-10). Therefore, the analytical results for these two trace elements are presented in Table 5. Furthermore, all of the results were initially measured in ppb (equivalent to ng g⁻¹) but have been converted to ppm (equivalent to ng mg⁻¹) for compatibility with other datasets. The 1/Sr ppm x 1000 calculation results are also presented in Table 5 as they will be analysed within the next chapter.

Starting with the strontium concentrations, ⁸⁷Sr was the most abundant isotope for both the RC⁻ and the RM³, yielding values of 35.80 ppm and 72.82 ppm, respectively. These two values are within the range of British variation (20 ppm to 180ppm) observed in archaeological samples from the Neolithic to the 19th century, and are both below the median concentration of 84 ppm (Evans *et al.* 2012). The strontium concentration measured in the RC⁻ is much lower than the concentration for the RM³ with a difference of 37.02 ppm between the two teeth. This earlier forming tooth is also at the lower end of the range for strontium concentrations observed in British samples, whilst the RM³ is closer to the median value. The implications of this difference between the teeth and potential reasons for it will be examined within the following chapter. Turning to the lead concentration results, the most abundant isotope for both teeth was ²⁰⁸Pb, with a value of 0.03 ppm obtained for the RC⁻ and 0.02 ppm for the RM³. Between the two teeth's concentration results there was a difference of only 0.01 ppm. These very low values are as expected for a prehistoric individual such as this Early Bronze Age person, with the median lead concentration for British enamel samples dating between the Neolithic and Iron Age proposed to be 0.07 ppm (Montgomery *et al.* 2010: 204-205). Additionally, as these values are within the range they are expected to be for British prehistoric individuals, this serves as testament that laboratory protocols in place to prevent contamination were upheld during both sample preparation and analysis, as contaminants from a modern polluted source would be expected to raise the measured lead

concentrations (Drasch 1982; Manea-Krichten *et al.* 1991). Like for the strontium concentrations, these ^{208}Pb concentrations and the probable reasons for them being so low will be expanded upon in Chapter 6.

Table 5: This table shows the results of the strontium and lead concentration measurements for both of the studied teeth

Sample	Sample number	^{87}Sr concentration (ppm)	1/Sr ppm x 1000	^{208}Pb concentration (ppm)
RC ⁻	9541	35.80	27.93	0.03
RM ³	9542	72.82	13.73	0.02

5.4 Carbon and Nitrogen Isotope Analysis Results

The incremental dentine collagen analysis results for the RC⁻ and RM³ have been separated into two tables (Table 6 and Table 7) for clarity due to the large number of values produced for each tooth. Within these tables, the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values are presented for each increment along with their associated total organic carbon and nitrogen content and C:N atomic ratio. All of the increment samples analysed yielded C:N ratios within the range of accepted values (2.9 – 3.6 or more securely between 3.1 – 3.5) indicating well-preserved collagen (DeNiro 1985; Ambrose 1999; van Klinken 1999), which suggests that the collagen from both teeth has not been significantly altered by post-mortem diagenesis (Beaumont *et al.* 2015). For the RC⁻, the $\delta^{13}\text{C}$ values ranged from -22.30‰ to -21.01‰ with a mean of -21.70‰, whilst the $\delta^{15}\text{N}$ values ranged from 10.41‰ to 12.40‰ and produced a mean of 11.44‰. Thus, the carbon and nitrogen isotope ratios measured in the RC⁻ both have a difference of above 1‰ (1.28 and 1.99, respectively), which is above analytical uncertainty at a 2σ range and suggests that these differences are significant and worth further investigation. In turn, the RM³ yielded $\delta^{13}\text{C}$ values ranging from -22.01‰ to -21.21‰ with a mean of -21.78‰, and $\delta^{15}\text{N}$ values ranging from 11.14‰ to 12.55‰ with a mean of 11.66‰. The difference between the RM³'s $\delta^{13}\text{C}$ values is 0.70‰, which is just slightly above analytical uncertainty at a 2σ range, whereas the difference between the $\delta^{15}\text{N}$ values (1.41‰) is significantly above analytical uncertainty at a 2σ range. Overall, the RC⁻ shows more variation in both its carbon and nitrogen isotope compositions than the RM³, producing both the highest and lowest $\delta^{13}\text{C}$ values and the lowest $\delta^{15}\text{N}$ value, although the RM³ does display the highest $\delta^{15}\text{N}$ value. Within the following chapter, these trends will be examined in more detail and the carbon and nitrogen isotope ratio results will be contextualised in relation to the results for the studied

populations within the Beaker People Project to explore whether the Oakslaw individual's diet is as expected for the Beaker period.

The bulk bone collagen sample was run in duplicate and the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ results are shown in Table 8 along with the total organic carbon and nitrogen content and the C:N atomic ratios. A mean $\delta^{13}\text{C}$ value of -22.02‰ was obtained from the duplicate samples alongside a mean $\delta^{15}\text{N}$ value of 10.93‰ . Like for the dentine increments, the C:N ratios for the bulk bone collagen were within the established range for well-preserved collagen (DeNiro 1985; Ambrose 1999; van Klinken 1999), and the duplicate samples only varied by 0.07‰ for carbon and 0.06‰ for nitrogen which is within analytical uncertainty at a 1σ range. In comparison to the dentine collagen of both teeth, the bone collagen has much lower mean $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values, showing a difference of 0.32‰ and 0.24‰ between the mean $\delta^{13}\text{C}$ values in the RC^- and RM^3 , respectively, and a difference of 0.51‰ and 0.73‰ between the RC^- and RM^3 's mean $\delta^{15}\text{N}$ values. These differences are considerably higher than the 0.08‰ difference between the mean $\delta^{13}\text{C}$ values and 0.22‰ difference between the mean $\delta^{15}\text{N}$ values of the two teeth. Finally, the enamel carbonate $\delta^{13}\text{C}$ values for both teeth, which were also measured in duplicate, are reported in Table 9. The RC^- enamel sample yielded a mean $\delta^{13}\text{C}$ value of -16.5‰ with a difference of 0.03‰ between the duplicate measurements. In comparison, the RM^3 enamel sample yielded a lower mean $\delta^{13}\text{C}$ value of -16.26‰ , with the duplicate samples varying by 0.1‰ . The difference between the mean carbon isotope ratio of the two teeth was 0.24 , which is just above analytical error at a 2σ range.

Table 6: The carbon and nitrogen isotope ratios measured in the RC- increments are shown here with the C:N atomic ratios and the total organic carbon and nitrogen content values

Sample	Sample number	Increment	%N	$\delta^{15}\text{N}$ (‰)	1 σ (‰)	%C	$\delta^{13}\text{C}$ (‰)	1 σ (‰)	C/N
RC- Dentine	9541	1 and 2	12.84	10.41	0.2	36.92	-22.30	0.2	3.4
		3	14.44	11.06	0.2	43.58	-21.94	0.2	3.5
		4	14.97	11.43	0.2	42.64	-21.53	0.2	3.3
		5	14.89	11.24	0.2	44.34	-21.44	0.2	3.5
		6	15.00	11.45	0.2	42.69	-21.01	0.2	3.3
		7	15.22	11.22	0.2	43.56	-21.21	0.2	3.3
		8	15.26	11.03	0.2	44.13	-21.58	0.2	3.4
		9	15.15	10.94	0.2	44.66	-21.45	0.2	3.4
		10	15.30	11.15	0.2	43.99	-21.35	0.2	3.4
		11	15.12	11.27	0.2	41.90	-21.47	0.2	3.2
		12	14.90	11.32	0.2	43.15	-21.21	0.2	3.4
		13	14.88	11.13	0.2	44.48	-21.41	0.2	3.5
		14	15.09	10.96	0.2	42.22	-21.40	0.2	3.3
		15	15.08	11.32	0.2	43.38	-21.76	0.2	3.4
		16	14.96	11.26	0.2	45.34	-21.77	0.2	3.5
		17	15.17	11.51	0.2	44.57	-21.73	0.2	3.4
		18	15.34	11.75	0.2	43.94	-21.89	0.2	3.3
		19	15.01	11.84	0.2	42.83	-21.96	0.2	3.3
		20	15.18	12.13	0.2	42.47	-21.99	0.2	3.3
		21	14.80	11.83	0.2	43.67	-22.29	0.2	3.4
		22	14.87	11.84	0.2	44.10	-22.09	0.2	3.5
		23	15.00	12.40	0.2	43.56	-22.17	0.2	3.4
		24 and 25	14.83	11.98	0.2	43.71	-21.90	0.2	3.4
		26 and 27	14.91	12.10	0.2	44.63	-22.06	0.2	3.5

Table 7: The carbon and nitrogen isotope ratios measured in the RM³ increments are shown here with the C:N atomic ratios and the total organic carbon and nitrogen content values

Sample	Sample number	Increment	%N	$\delta^{15}\text{N}$ (‰)	1 σ (‰)	%C	$\delta^{13}\text{C}$ (‰)	1 σ (‰)	C/N
RM ³ Dentine	9542	1	13.60	11.14	0.2	37.81	-21.73	0.2	3.2
		2	14.43	11.29	0.2	41.06	-21.76	0.2	3.3
		3	14.91	11.53	0.2	43.64	-21.96	0.2	3.4
		4	15.07	11.53	0.2	42.63	-21.95	0.2	3.3
		5	14.71	11.51	0.2	41.90	-21.79	0.2	3.3
		6	15.00	11.68	0.2	42.85	-21.97	0.2	3.3
		7	15.23	11.37	0.2	43.64	-21.87	0.2	3.3
		8	15.24	11.28	0.2	43.80	-21.72	0.2	3.4
		9	14.94	11.21	0.2	44.18	-21.44	0.2	3.4
		10	15.16	11.29	0.2	44.57	-21.31	0.2	3.4
		11	15.18	11.59	0.2	44.62	-21.85	0.2	3.4
		12	15.00	11.97	0.2	42.61	-21.68	0.2	3.3
		13	14.77	12.55	0.2	42.47	-21.70	0.2	3.4
		14	15.07	12.26	0.2	42.36	-22.01	0.2	3.3
		15	14.51	12.40	0.2	41.14	-21.75	0.2	3.3
		16	14.96	12.00	0.2	43.02	-22.00	0.2	3.4

Table 8: The carbon and nitrogen isotope ratios measured in the duplicate bulk bone samples are shown here with the C:N atomic ratios and the total organic carbon and nitrogen content values

Sample	Sample number	%N	$\delta^{15}\text{N}$ (‰)	1 σ (‰)	%C	$\delta^{13}\text{C}$ (‰)	1 σ (‰)	C/N
Bulk Bone	9540	14.19	10.90	0.2	41.77	-21.99	0.2	3.4
	9540r	14.35	10.96	0.2	42.75	-22.06	0.2	3.5

Table 9: The carbon isotope ratios measured in the enamel of the two teeth are shown here

Sample	Sample number	Equivalent Calcium Carbonate Content (%)	$\delta^{13}\text{C}_{(\text{VPDB})}$ (‰)	Mean $\delta^{13}\text{C}_{(\text{VPDB})}$ (‰)	1 σ (‰)
RC ⁻ Enamel	9541	4.7	-16.18	-16.15	0.05
		3.8	-16.12		
RM ³ Enamel	9542	4.3	-16.32	-16.26	0.09
		3.5	-16.20		

6. Discussion

6.1 Provenance Assessment Using Strontium and Oxygen Isotopes

6.1.1 Locality in Relation to Rock

Since it has been established that both the oxygen and strontium isotope ratios of the Oakslaw individual's RC⁻ and RM³ are consistent with a British origin, with the oxygen isotope ratios suggesting an origin on the eastern side of Britain in particular, it is important to relate this to the values expected for Rock and the surrounding area to determine whether the individual was likely local to their place of burial. According to the BGS isotope domain map (2022a), strontium isotope ratios ranging from 0.7088-0.7101 and $\delta^{18}\text{O}_\text{p}$ values between 16.55‰ and 17.85‰ from human enamel samples are expected for an origin consistent with Rock, with these ranges formed by extrapolating empirical data from the biosphere $^{87}\text{Sr}/^{86}\text{Sr}$ distribution map of Britain (Evans *et al.* 2010: see Figure 14) and $\delta^{18}\text{O}_\text{p}$ values measured in archaeological human enamel samples (Evans *et al.* 2012). Thus, if these extrapolated ranges are deemed to be accurate for Rock, this would suggest that the Oakslaw individual's $\delta^{18}\text{O}_\text{p}$ values for both teeth are consistent with a local origin, whilst the strontium isotope ratios both fall outside the expected range and are too high for the Sedimentary limestone, sandstone, and mudstone bedrock formed during the Carboniferous period that underlies Rock (BGS 2022b). Instead, when the measured oxygen and strontium isotope ratios for each tooth are entered into the map's sample query together, the RC⁻ values are suggested to be consistent

with an origin in areas closer to Rock than the RM³ (Figure 17), such as coastal areas to the east and south-east as well as the lower lying areas at the base of the Cheviot Hills (BGS 2022a). Conversely, whilst the strontium and oxygen isotope ratios from the RM³ also suggest a coastal origin to the south-east of Rock, they are also largely consistent with the upland areas of the Cheviot Hills (Figure 18) (BGS 2022a). This therefore suggests that the Oakslaw individual could have spent their life within 45 miles of Rock and could be classified as “local” to the area in that sense, but may have moved around the region throughout their lifetime before being buried at Rock itself. Similar potential short-distance movements were identified in the BPP for individuals found in Scotland, where like Northumberland the underlying geology is complex and highly variable so can yield significantly different strontium isotope ratios across small distances (Parker Perason *et al.* 2016). Regardless of the scale of this movement, however, its possibility is still important to consider, especially as the Cheviot Hills in particular have previously been suggested to have been a centre for exchange, burial, and communication for EBA populations in the North-East and beyond (Fowler and Wilkin 2016), thus potentially placing this individual and their life

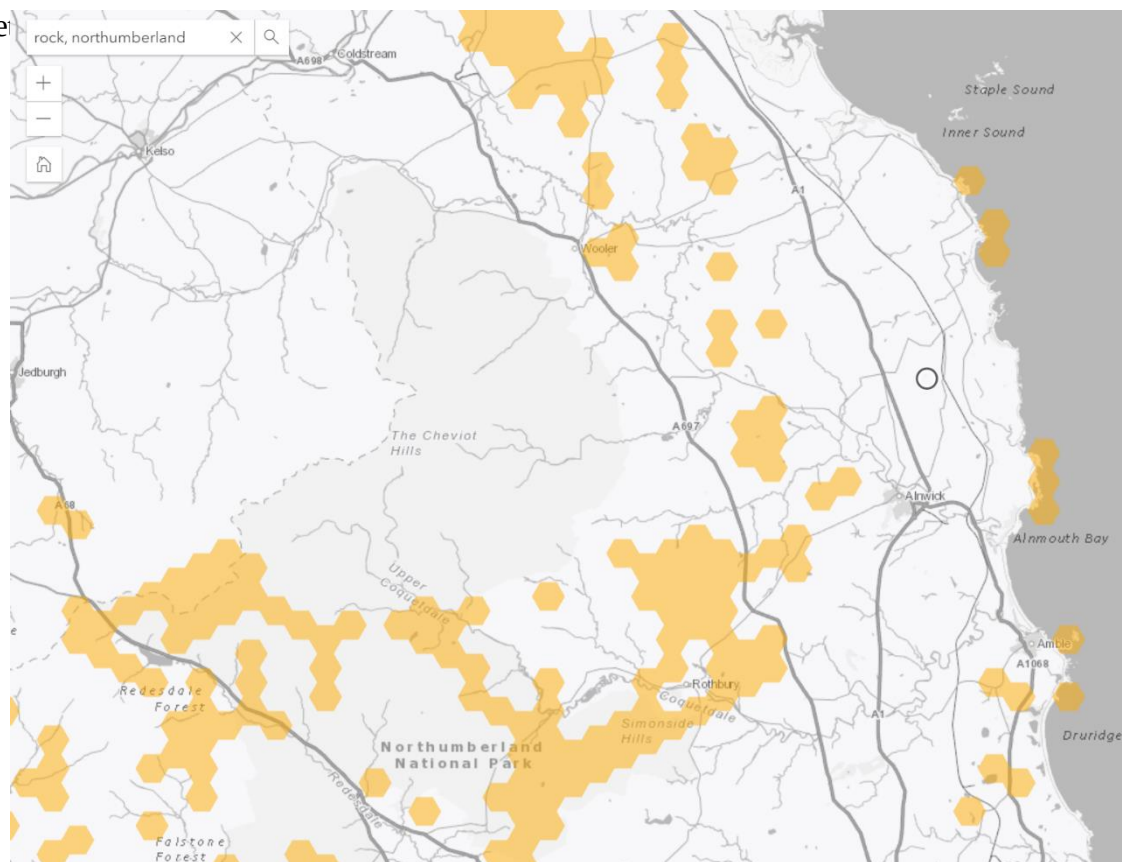


Figure 17: The highlighted areas of the map show the areas within a 45-miles radius of Rock (black circle) that are consistent with the strontium and oxygen isotope ratios of the RC- (BGS 2022a)

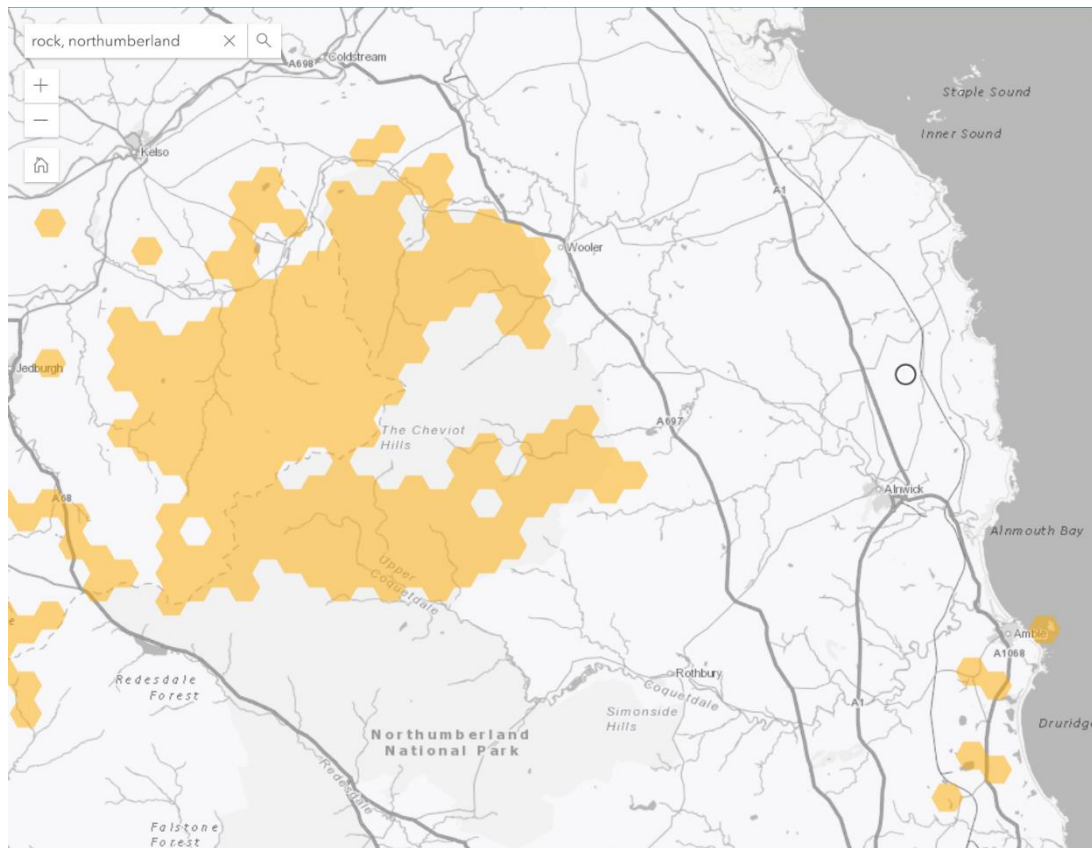


Figure 18: The highlighted areas of the map show the areas within a 45-miles radius of Rock (black circle) that are consistent with the strontium and oxygen isotope ratios of the RM³ (BGS 2022a)

However, as the expected strontium isotope range identified by the BGS dataset is not based on sample measurements taken specifically from Rock and is also given as an expected range for most of England's north-east coast (BGS 2022a), it may perhaps be more credible to infer this individual's provenance using empirical data from a known source. For instance, strontium isotope ratios measured in the enamel of modern feral cattle from Chillingham (Towers 2013) may be used as a proxy from which to infer locality to Rock, as Chillingham is only 12 miles north-west of Rock and sits on the same underlying geology (BGS 2022b). The Chillingham cattle all lived in the same enclosed area and had access to the same food sources (Towers 2013), thus representing a population of individuals with very restricted mobility and dietary inputs, with their strontium isotope ratio compositions shown to be mainly dominated by the input of two end-members: the local geology and precipitation levels (Capo *et al.* 1998; Montgomery *et al.* 2007). From these cattle enamel samples, a range of strontium isotope ratios between 0.71032-0.71094 was obtained (Towers 2013), which if used as a proxy for Rock would overlap with the RM³'s $^{87}\text{Sr}/^{86}\text{Sr}$ value and thus suggest that

the Oakslaw individual was potentially local to Rock whilst this later-developing tooth was forming in the years before their death and burial at Oakslaw, The RC⁻ still sits outside this range however, although as the Chillingham cattle $^{87}\text{Sr}/^{86}\text{Sr}$ values vary by up to 0.00062 despite their limited roaming space, it is possible that the 0.000832 difference between the RC⁻ and RM³ may similarly be due to natural biological variation in the available biosphere strontium (Montgomery *et al.* 2007), and may not necessarily infer a significant movement by this individual between their childhood residence and place of burial. These inferences made using the Chillingham cattle dataset are therefore in slight contrast to those inferred from the BGS dataset, highlighting the difficulty of accurately interpreting isotope analysis results, the discrepancies between interpretations that can arise depending on the comparative data used, and the importance of acknowledging all possibilities suggested by the data. Ultimately, as using stable isotope analysis to provenance an individual is an exclusionary method that can rule out areas as potential residential origins but cannot confirm one specific location (Montgomery and Jay 2013), it can confidently be concluded that the combined strontium and oxygen isotope ratios of the Oakslaw individual's teeth exclude the west side of Britain and areas with underlying geology producing both very low $^{87}\text{Sr}/^{86}\text{Sr}$ values (such as the Cretaceous Chalk of South-East England) and high $^{87}\text{Sr}/^{86}\text{Sr}$ values (like the metamorphic bedrock of Scotland) (Evans *et al.* 2010; 2012) as possible origins for childhood and later adolescence. However, unfortunately as the RM³'s $^{87}\text{Sr}/^{86}\text{Sr}$ value falls into the undiagnostic “strontium range of doom” between 0.7092-0.7110, which denotes strontium isotope ratios commonly generated from many areas of Britain and Europe due to similar underlying geologies (Montgomery *et al.* 2014), it must be recognised that although this tooth's strontium isotope ratio composition is within the Chillingham cattle range and otherwise consistent with the geology surrounding Rock, this limitation of isotope analysis means that it would not be valid to assign Rock as the only possible residential origin during the individual's adolescence (Montgomery and Jay 2013). Despite this, whilst this isotope evidence suggests possible origins away from Rock and also implies potential mobility between childhood and later adolescence, the strontium and oxygen isotope ratios in both teeth are nevertheless consistent with Rock and its surrounding region of variable geology, thus supporting the Oakslaw individual as likely being local to this area of North-East England. Lastly, as an additional brief consideration, the $^{87}\text{Sr}/^{86}\text{Sr}$ value of the RM³ shows a shift towards seawater value and the $\delta^{18}\text{O}_\text{p}$ value is slightly lower in comparison to the RC⁻, therefore raising the possibility that these observed differences between the teeth do not correlate to mobility but instead to seasonality and their different times of formation, with the

enamel of the RM³ potentially developing during a period of wetter and cooler conditions such as winter that would dampen the ⁸⁷Sr/⁸⁶Sr values and lower the δ¹⁸O_p values; and the RC⁻ enamel developing during a warmer and drier period such as summer (Dansgaard 1964; Capo *et al.* 1998; Towers *et al.* 2014).

6.1.2 The Oaksław Individual's Locality within the Context of the BPP Dataset

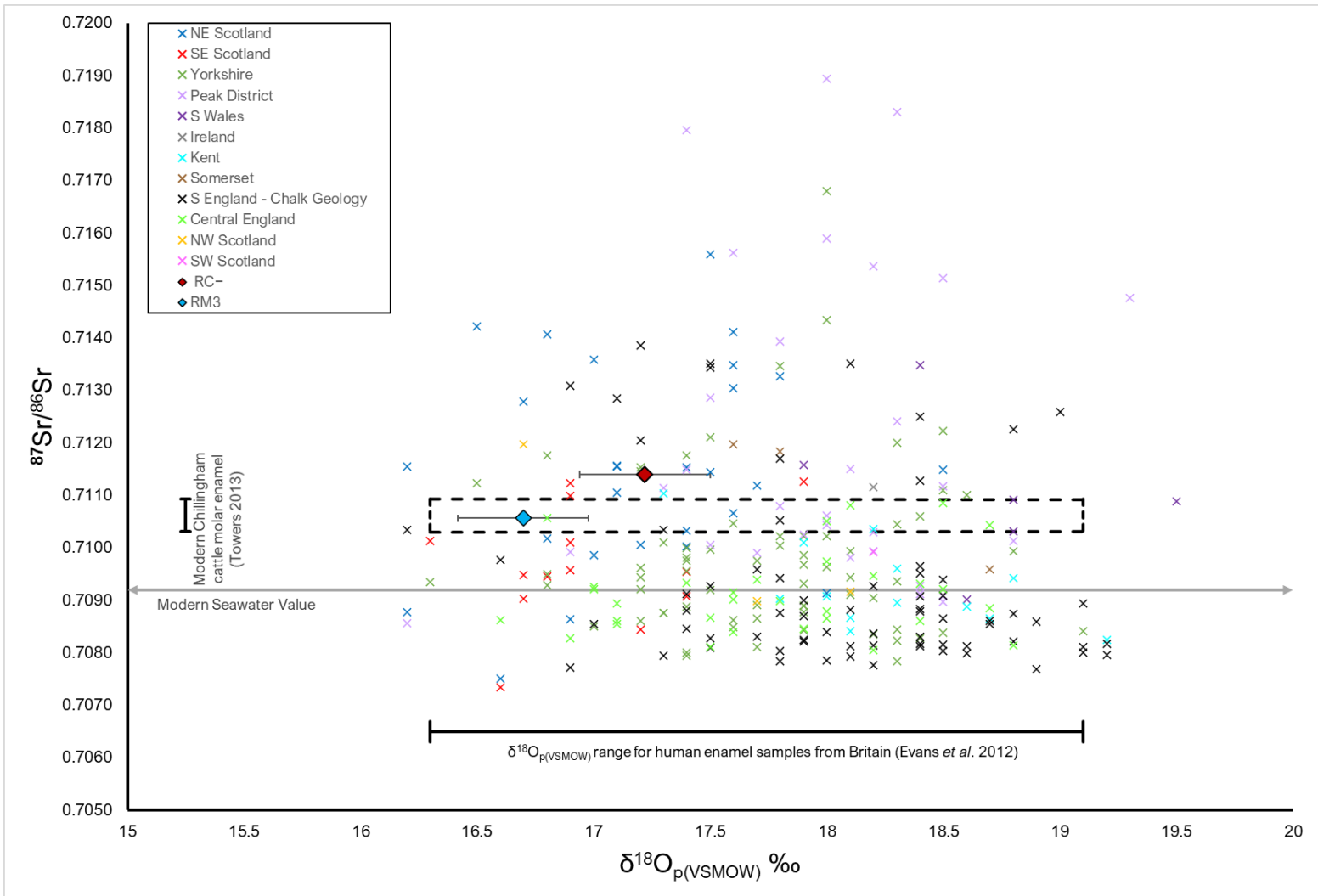


Figure 19: The strontium and oxygen isotope ratios for the two teeth have been plotted together with the BPP data. The dotted box includes the range of strontium isotopes inferred to be local to Rock based on the Chillingham cattle dataset (Towers 2013), as well as the range of oxygen isotope ratios expected for Britain (Evans *et al.* 2012). The value for seawater is also included and the size of the symbols include analytical error for strontium at 1σ

The combined strontium and oxygen isotope results for the Oaksław individual are shown in Figure 19 alongside the 267 individuals from the BPP dataset for which both ⁸⁷Sr/⁸⁶Sr and δ¹⁸O_p values were available (Parker Pearson *et al.* 2019; Montgomery *et al.* 2019b). ⁸⁷Sr/⁸⁶Sr values for the Chillingham cattle (Towers 2013) were used in this comparative graph as empirical data representing the expected local strontium isotope ratio range for Rock,

although as previously mentioned values both above and below this range may also be consistent with a local origin due to Northumberland's complex geology. Additionally, the range of $\delta^{18}\text{O}_p$ values from human tooth enamel expected for Britain (Evans *et al.* 2012) was included within the graph to highlight the spread of the BPP individuals across this range and to show where the Oakslaw individual lies within this variation. The $^{87}\text{Sr}/^{86}\text{Sr}$ value for modern seawater (0.7092) was also added to Figure 19 to emphasise that the strontium isotope ratios of both the RC^- and RM^3 are considerably higher than this value, whilst the BPP dataset includes individuals with $^{87}\text{Sr}/^{86}\text{Sr}$ values very close to that of seawater as well as those lower and significantly higher than it too. Within this comparative dataset at least one individual from all twelve location groups was represented, although individuals excavated from Yorkshire and the Cretaceous Chalk of southern England dominate, together making up over half the samples in the dataset with their respective representation of 25.1% and 26.2% of the 267 individuals (Montgomery *et al.* 2019b). With this excavation bias in mind, the $^{87}\text{Sr}/^{86}\text{Sr}$ values in the BPP dataset ranged between 0.7073-0.7189, with a mean of 0.7100 and a variation of 0.0116 between the maximum and minimum values. The $\delta^{18}\text{O}_p$ values ranged between 16.2‰ to 19.5‰, with a variation of 3.3‰ and a mean of 17.8‰, which is almost the same as the proposed mean of 17.7‰ for British enamel samples from the Neolithic period to the 19th century (Evans *et al.* 2012).

In the BPP dataset, the Oakslaw individual would represent the first individual excavated in the north-east of England to be studied (Parker Pearson *et al.* 2019), and would therefore expand the coverage of the dataset by allowing for the creation of an additional location group between south-east Scotland and Yorkshire which contemporary individuals excavated from the region in the future could be added and compared to. Moreover, as this individual has been inferred to be local to the north-east region, the strontium and oxygen isotope composition of their teeth could be used as a local reference baseline alongside other empirical data from the region, such as the Chillingham cattle (Towers 2013) and the Anglo-Saxon individuals within Bamburgh's Bowl Hole cemetery isotopically identified as locals (Groves *et al.* 2013). This would not only allow newly discovered skeletons from the North-East to be compared to multiple empirical data sources to infer whether they are local to the region, but may also be useful to investigate whether the many individuals in the BPP dataset identified as non-locals could potentially have an origin consistent with the north-east of England. For instance, burials from Yorkshire and the Peak District were found to have highly variable strontium isotope ratios and a wide range of $\delta^{18}\text{O}_p$ values, indicating a

significant proportion of non-local individuals within the burial populations and leading to the suggestion that these regions were potentially focal points for long-distance migration and/or burial centres for Beaker populations across England (Montgomery *et al.* 2019a). As an example potentially worthy of further investigation, five non-local individuals excavated in Yorkshire were identified as notable outliers due to low $\delta^{18}\text{O}_\text{p}$ and non-chalk $^{87}\text{Sr}/^{86}\text{Sr}$ values (Montgomery *et al.* 2019a: 398), with some of them displaying oxygen and strontium isotope ratios consistent with those expected for the North-East based on the Oakslaw individual's results and other established reference materials (Evans *et al.* 2010; 2012; BGS 2022a), although of course other origins are possible due to the overlap of expected oxygen and strontium isotope ratios for many areas of Britain (Montgomery *et al.* 2019a; Pellegrini *et al.* 2019) and should be acknowledged if this was explored further. Therefore, in summary, as the BPP identified significant levels of mobility (both short and long-distance) within the studied burial populations (Montgomery *et al.* 2019), the Oakslaw individual potentially represents an example of short-distance movement within a particular region, and at the very least expands the geographical coverage of this already extensive empirical dataset. Furthermore, the interpretation of this individual as being local to Rock and the surrounding region in Northumberland highlights the benefits of inferring mobility and locality using a multi-isotope approach as practiced in the BPP, and also ultimately supports the publication's emphasis that provenance studies using strontium and oxygen isotope ratios are limited by the issue of equifinality, with residential origins only ever being able to be suggested not confirmed (Montgomery *et al.* 2019; Pellegrini *et al.* 2019).

6.2 Strontium and Lead Concentrations in a Bronze Age Context

The BPP dataset shows a wide variation of enamel strontium concentrations across the location groups, with the strontium concentration of the RM³ falling closer to the dataset's mean (65.26 ppm) than the RC⁻, which lies closer to the minimum measured concentration of 14.73 (Montgomery *et al.* 2019a). Enamel strontium concentrations for these two teeth have been converted onto a non-linear scale using the equation $[1/\text{Sr ppm} * 1000]$ and plotted against their associated $^{87}\text{Sr}/^{86}\text{Sr}$ values to further investigate the provenance of the Oakslaw individual (Figure 20). The same measurements for each location group of the BPP dataset were also added to the graph for comparison (Montgomery *et al.* 2019a), as well as those for the Chillingham cattle (Towers 2013), with higher concentrations represented by lower (less

positive) values. This form of graph is useful to investigate potential mixing models, and within it the Chillingham cattle population can clearly be seen to form a mixing line in a probable two end-member system as previously suggested, with their $^{87}\text{Sr}/^{86}\text{Sr}$ values seemingly decreasing slightly towards seawater value (0.7092) and away from the geological strontium isotope input (which is likely to be around 0.7110 or above) as their concentrations increase. Although this reference cattle population includes eight samples and there are only two enamel samples for the Oakslaw individual, the pairing of the RC^- and RM^3 strontium isotope ratios and inverse concentrations on the graph potentially shows a similar mixing line to the Chillingham cattle. The RM^3 displays a lower $^{87}\text{Sr}/^{86}\text{Sr}$ value closer to seawater (the source of precipitation and drinking water) and a higher strontium concentration, whilst the RC^- displays a lower concentration and higher $^{87}\text{Sr}/^{86}\text{Sr}$ value possibly closer to the values for the geological terrain from which the individual sourced their food. Combining this with the previous interpretations made using the strontium and oxygen isotope ratios, it is therefore possible that both the RC^- and RM^3 are consistent with a local origin in the region surrounding Rock but display variation in their strontium isotope ratios that lies between the upper end-member of the local complex geology and the lower end-member of seawater due to the nature of Britain as a maritime environment and Rock's close generally close location to the coast (roughly 5 miles today) (Montgomery *et al.* 2007). This could also support the idea that the RC^- enamel developed during a drier period with lower precipitation levels preventing the dampening of the strontium isotope ratio to the same extent seen in the RM^3 . Similar two end-member systems with inputs from local geology and seawater-derived drinking water have been observed for other Bronze Age populations from England in the Yorkshire Wolds and the Pennines, and were suggested to represent sedentary agricultural communities procuring their food from the local geology only (Montgomery *et al.* 2007). Thus, based on oxygen and strontium isotope ratios and strontium concentrations, it could be suggested that the Oakslaw individual represents a sedentary individual who lived near Rock and sourced their food locally, although the complex nature of interpreting isotope and trace element analysis results restricts the confidence with which this inference can be made (Parker Pearson *et al.* 2019b).

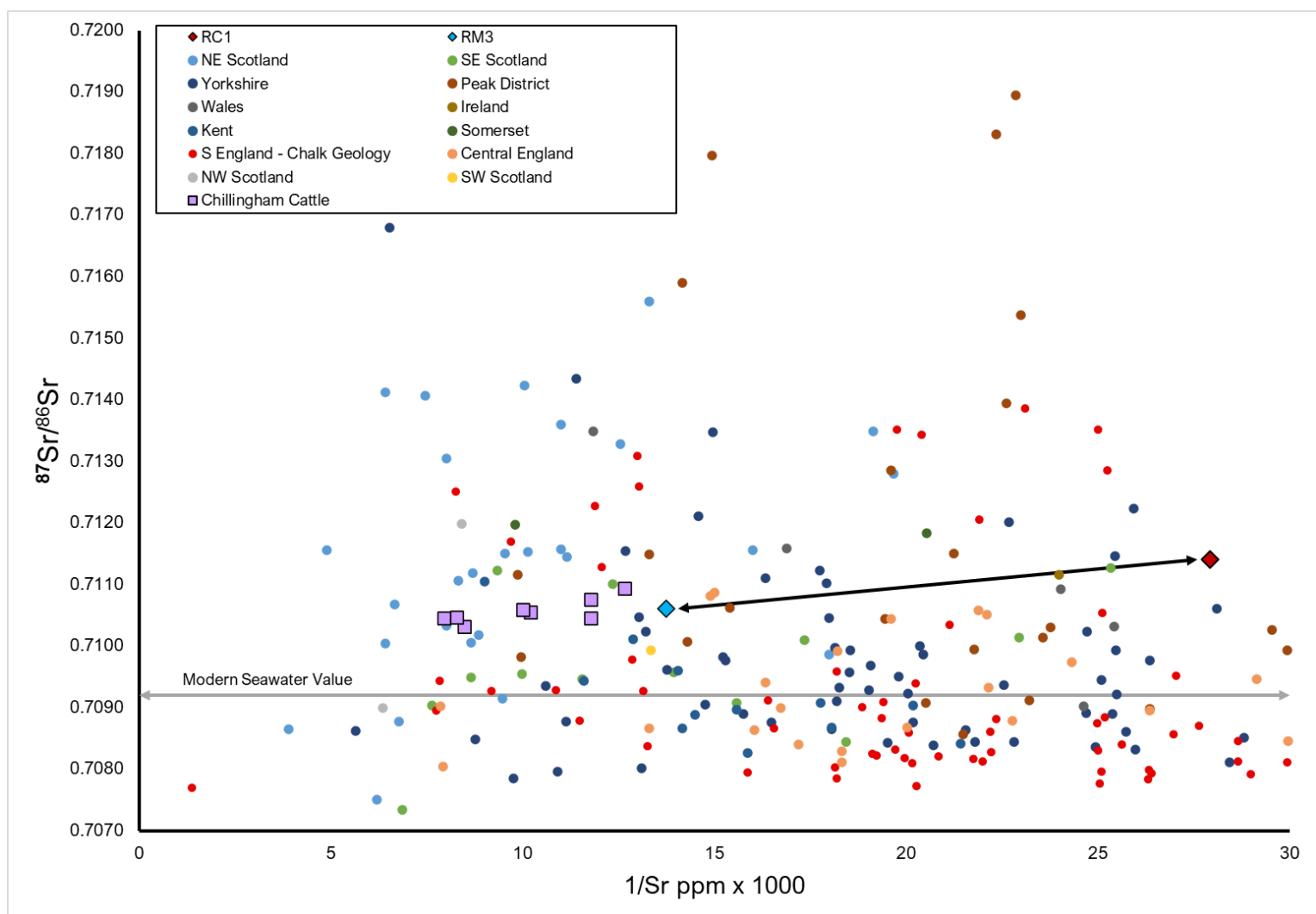


Figure 20: This graph plots the inverse strontium concentrations against their associated strontium isotope ratio. The two teeth are paired by the arrow, and the Chillingham cattle are represented by the purple squares. The BPP data are also included for all location groups. The size of the symbols includes analytical error at 1σ

As previously mentioned, the low ^{208}Pb concentrations in booth teeth are as expected for an individual from prehistoric Britain and fall at the lower end of the range of published contemporary data (Montgomery *et al.* 2005; 2010). These values are likely to be so low due to them being derived from non-anthropogenic environmental lead sources that the Oakslaw individual had been naturally exposed to throughout the enamel's development (Budd *et al.* 2000), and are in stark contrast to the high concentrations seen in later lead-using populations such as the Romans (Montgomery *et al.* 2005; 2010). As a chronologically and spatially related comparative example mentioned in the BPP, the Gristhorpe Man excavated in North Yorkshire yielded a lead concentration of 0.003 ppm deemed to be the lowest concentration measured in British tooth enamel (Montgomery and Gledhill 2013). Thus, as the Oakslaw individual's enamel lead concentration is higher than this lowest value but lower than the observed median value of 0.07 ppm for British prehistoric samples (Montgomery *et al.* 2010), this advocates that they resided in an environment largely free of lead pollution and supports the radiocarbon dating of the individual to the EBA period (Montgomery and Gledhill 2013).

6.3 Palaeodietary Reconstruction and BPP Comparison

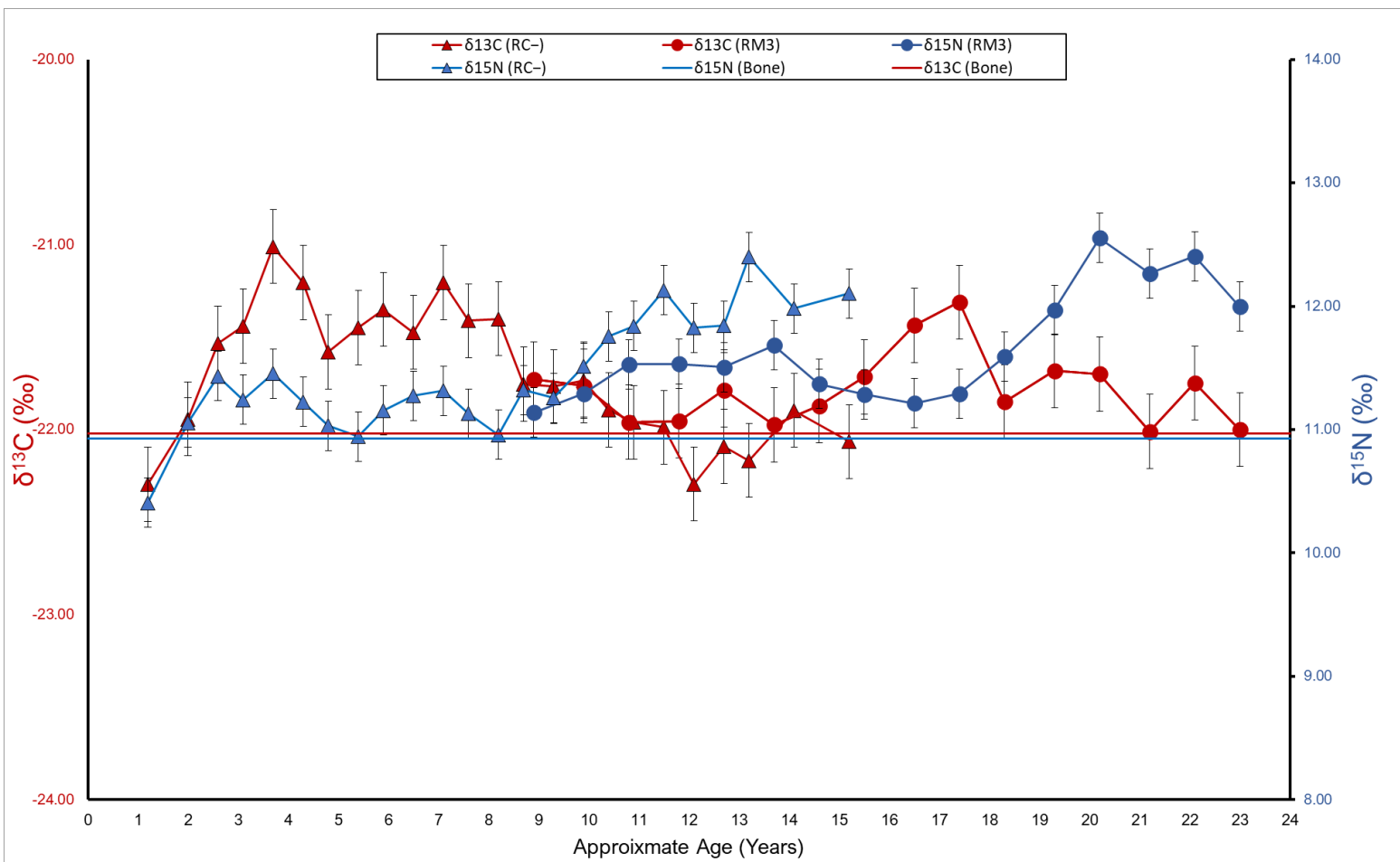


Figure 21: The incremental dentine profiles for both teeth have been plotted together here with the mean bone carbon and nitrogen isotope ratios. The error bars represent analytical error at 1σ .

The incremental dentine profiles for the RC⁻ and the RM³ were combined and are presented in Figure 21 with the mean carbon and nitrogen isotope ratios from the bulk bone sample. Starting with the RC⁻, the $\delta^{13}\text{C}$ values increase from -22.30‰ at the start of tooth formation at approximately 7.5 months until around 2.5 years old where they remain fairly constant between -21.58‰ and -21.01‰ before gradually decreasing after 8 years old to similar values as the start of the $\delta^{13}\text{C}$ profile, once again remaining stable until the tooth's growth is arrested at 14-15 years of age. Similarly, the $\delta^{15}\text{N}$ values for this tooth increase slightly from 10.41‰ to 11.06‰ at the start of development and do not vary much between 2-9 years of age, although at the end of the profile the $\delta^{15}\text{N}$ values increase quite significantly and remain constant until the profile's end, with a peak of 12.40‰ around 13 years old. In comparison, the RM³'s incremental profile shows less variation, with $\delta^{13}\text{C}$ values remaining stable between -21.96‰ and -21.72‰ from 8.5-15.5 years old before increasingly slightly to -

21.31‰ around 17 years, then declining back down to similar values as before the rise until the end of the profile and the death of the individual between 18-24 years old. The $\delta^{15}\text{N}$ values remain fairly constant throughout the whole profile, save for a slight peak at around 13 years old and a significant increase over the last six increments with approximate ages of 18-24 years old, although as the exact age-at-death is unknown and the RM^3 's root apex was not fully closed, these ages for the increments must be treated with caution. The $\delta^{13}\text{C}$ values of both teeth seem to match quite well during the overlapping period of formation between approximately 8.5-14.5 years old, whilst the $\delta^{15}\text{N}$ values also roughly follow the same pattern of a peak around 13 years but display slightly more variation, with the RC^- having more elevated $\delta^{15}\text{N}$ values than the RM^3 . This variation is expected however, as dentine in the two teeth mineralise at different rates and so increments with similar approximate ages represent values averaged over different lengths of time (Crowder *et al.* 2019). Additionally, as the RM^3 was in the middle of its development at around 13 years whilst the RC^- was almost complete, the difference between the $\delta^{15}\text{N}$ values at this peak may be due to the continued deposition of dentine with lower $\delta^{15}\text{N}$ values in the RM^3 following the peak that depress the increment's averaged value compared to the one-way averaging in the RC^- (Beaumont and Montgomery 2016). Overall, the incremental profiles were quite difficult to interpret, with the fairly constant $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values observed over many of the increments suggesting a consistent diet, and the increased $\delta^{15}\text{N}$ values at the end of both teeth's profiles (approximately between ages 10-15 and 18-24) inferred as potential periods of stress possibly due to insufficient nutrition in the diet or illness (Beaumont and Montgomery 2016; Beaumont *et al.* 2015).

In combination with the BPP's dentine and bone values, the mean $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values for both teeth and the bulk bone sample are presented in Figure 22. As all the $\delta^{13}\text{C}$ values measured in the dentine increments and the duplicate bone samples were below 20‰, this implies the Oakslaw individual likely had a purely C_3 -based terrestrial diet with no significant marine resource consumption (Bonsall *et al.* 2009). Unfortunately, no animal remains were associated with the burial, so it was not possible to establish a faunal isotopic baseline for the site (Redfern *et al.* 2010). However, Jay and Richards (2019) compiled a comparative dataset of animal data for the BPP, which generated an average $\delta^{15}\text{N}$ value of $6.2\text{‰} \pm 0.5\text{‰}$ for herbivores from non-chalk geologies. The difference between this mean herbivore value and the mean $\delta^{15}\text{N}$ values of the RC^- , RM^3 , and bulk bone is 5.2‰, 4.9‰, and 3.8‰, respectively, which is largely consistent with the ~3-5‰ increase expected for a

trophic level shift (Bocherens and Drucker 2003), and thus suggests the Oaksław individual was omnivorous and consumed terrestrial herbivores. This fits with the omnivorous diet with high levels of animal protein consumption and no significant marine protein consumption identified for most individuals across Britain in the BPP (Jay and Richards 2019).

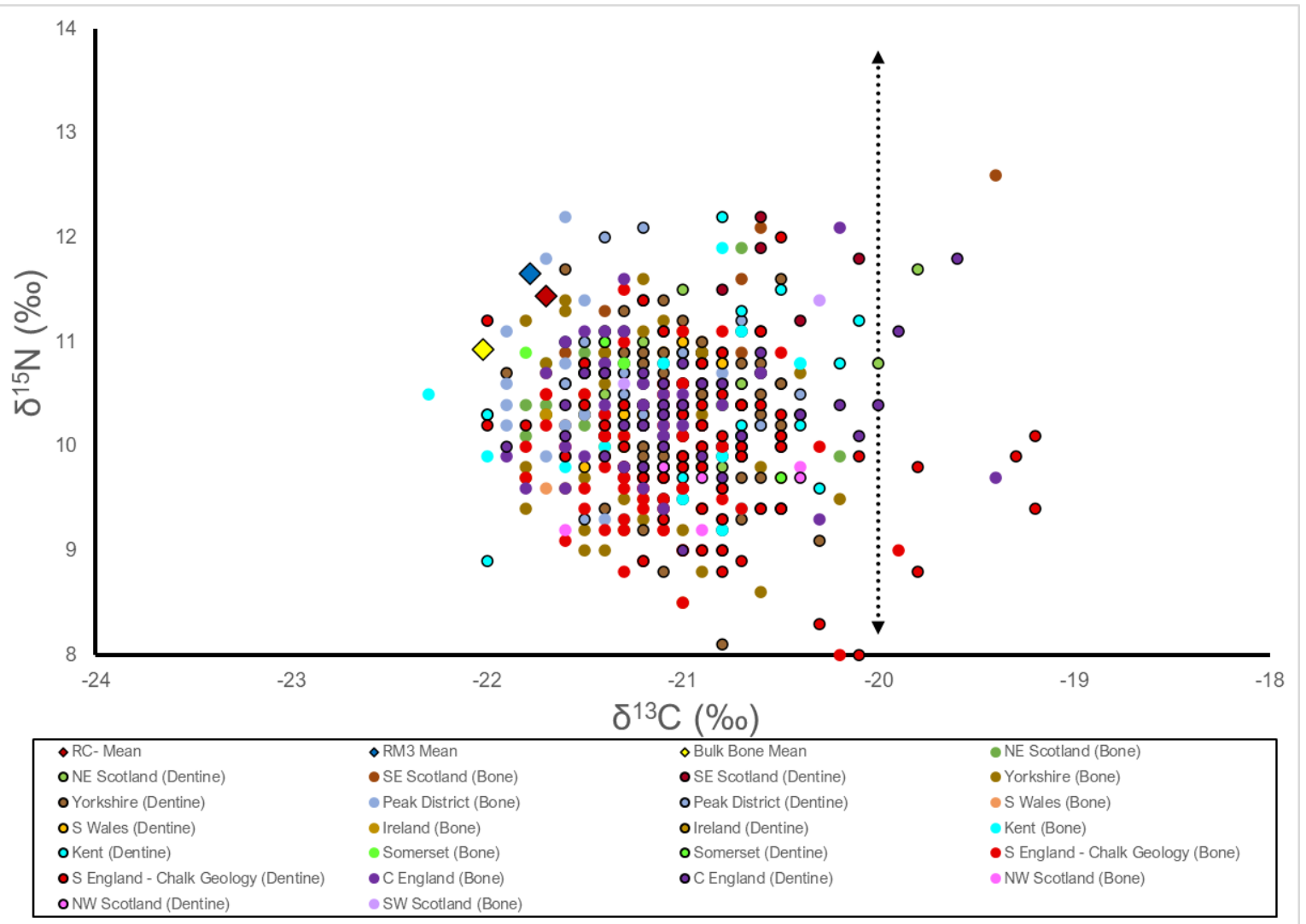


Figure 22: The mean carbon and nitrogen isotope ratios for the Oaksław individual's teeth and bulk bone sample are plotted here alongside the dentine and bone values from the BPP dataset. The dotted line represents the proposed upper boundary for a purely terrestrial diet (Bonsall *et al.* 2009)

6.4 Representation for North-East England

As it has been established that the Oaksław individual likely represents the first skeleton excavated in and likely to be local to the North-East within the BPP, it is also important to briefly consider how else this individual can contribute to this dataset. Firstly, with a probable

death in late adolescence or early young adulthood and an assigned sex as a probable male, this individual would increase the representation of this demographic, which is important as many individuals of this age category within the dataset do not also have a sex estimation (Parker Pearson *et al.* 2019). Additionally, as early forming teeth such as canines were largely avoided in the BPP to restrict potential effects of breastfeeding on oxygen isotope ratios (Montgomery *et al.* 2019a), the usefulness of the RC⁻ here in helping to infer locality highlights the value of using these teeth in combination with later-forming ones to construct high-resolution incremental profiles. Lastly, as the interment of this individual on their right side is more typical of female than male EBA burials (Dyer 2002), this may represent a regionally-specific burial tradition that could add to and be compared with those previously identified in the dataset (Parker Pearson *et al.* 2019). Of course, one individual cannot accurately represent an entire regional population, but as a rare example of a preserved articulated skeleton from the acidic soils of Northumberland, the analysis of the Oakslaw individual nevertheless advocates for the creation of an additional location group in the BPP which future studies should aim to expand.

7. Conclusion

The study of the Oakslaw individual represented a unique opportunity to not only analyse a rare example of preserved skeletal remains from Northumberland, but to also contribute new results to a publication as ambitious and comprehensive as the BPP. Indeed, the osteological re-assessment supported the affectionate name of the “Furry Beaker Man” with an assignment of a probable male sex, and also confirmed previous analyses’ age-at-death estimations of 18-25 years. A locality to Rock for both studied teeth was consistent with the strontium and oxygen isotope ratios, indicating that whilst other origins are possible, it is likely that this individual spent most of their life in the North-East and potentially travelled around the region before their death and burial at Rock. Comparisons of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values led to the identification of a probable omnivorous diet predominantly composed of terrestrial herbivore consumption and no significant marine resource consumption in line with the general diet observed in the BPP, as well as possible periods of nutritional stress in the complex incremental dentine profiles of the two teeth. However, like with all scientific studies, the credibility of these interpretations were restricted by limitations of the methods used to construct them, therefore advocating the need for further work such as peptide

analysis to confirm the individual's sex (Stewart *et al.* 2017) or a closer investigation of the incremental profiles and the skeleton to infer whether the periods of nutritional stress were severe and prolonged enough to cause skeletal changes. Additionally, as it was not possible to explore every aspect of the results in detail within the scope of this study, the carbonate enamel and bone collagen analysis results could be explored further. Nevertheless, the presented data and discussion meet the proposed aims of using a multidisciplinary approach to explore the Oakslaw individual's life history, significance within the BPP, and contributions to understanding of EBA lifestyles, with the main contribution of this study lying in its nature as the first investigation of an EBA individual from North-East England within the BPP, ultimately advocating the possibility and cruciality of expanding the dataset for this region.

Bibliography

- AlQahtani, S., 2009. An Atlas of Dental Development and Eruption. London: Queen Mary College, University of London
- Ambrose, S.H., 1990. Preparation and Characterisation of Bone and Tooth Collagen for Isotopic Analysis. *Journal of Archaeological Science*, 17(1), 431-451
- Bataille, C., von Holstein, I., Laffoon, J., Wilmes, M., Liu, X., Davies, G., 2018. A Bioavailable Strontium Isoscape for Western Europe: A Machine Learning Approach
- Beaumont, J., Lee-Thorp, J., Montgomery, J., 2013. Childhood Diet: A Closer Examination of the Evidence from Dental Tissues Using Stable Isotope Analysis of Incremental Human Dentine. *Archaeometry*, 55(2), 277-295
- Beaumont, J., Gledhill, A., Montgomery, J., 2014. Isotope Analysis of Incremental Human Dentine: Towards Higher Temporal Resolution. *Bulletin of International Association of Paleodontology*, 8(2), 212-223
- Beaumont, J., Montgomery, J., 2015. Oral Histories: A Simple Method of Assigning Chronological Age to Isotopic Values from Human Dentine Collagen. *Annals of Human Biology*, 42(4), 407-414
- Beaumont, J., Montgomery, J., Buckery, J., Jay, M., 2015. Infant Mortality and Isotopic Complexity: New Approaches to Stress, Maternal Health, and Weaning. *American Journal of Biological Anthropology*, 157(3), pp. 441-457
- Beaumont, J., Montgomery, J., 2016. The Great Irish Famine: Identifying Starvation in the Tissues of Victims Using Stable Isotope Analysis of Bone and Incremental Dentine Collagen. *PLoS ONE*, 11(8), pp. 1-21
- Bentley, R.A., 2006. Strontium Isotopes from the Earth to the Archaeological Skeleton: A Review. *Journal of Archaeological Method and Theory*, 13(1), pp. 135-187
- Blum, J.D., Taliaferro, E.H., Weisse, M., Holmes, R., 2000. Changes in Sr/Ca, Ba/Ca, and $^{87}\text{Sr}/^{86}\text{Sr}$ Ratios Between Trophic Levels in two Forest Ecosystems in the Northeastern USA. *Biogeochemistry*, 49(1), pp. 87-101

- Bocherens, H., Drucker, D., 2003. Trophic Level Isotopic Enrichment of Carbon and Nitrogen in Bone Collagen: Case Studies from Recent and Ancient Terrestrial Ecosystems. *International Journal of Osteoarchaeology*, 13(1), pp. 46-53
- Bonsall, C., Cook, G., Pickard, C., McSweeney, K., Bartosiewicz, L., 2009. "Dietary Trends at the Mesolithic-Neolithic Transition in Northwest Europe" in Crombe, P., van Strydonck, M., Sergeant, J., Boudin, M., Bats, M. (eds.) *Chronology and Evolution within the Mesolithic of North-West Europe: Proceedings of an International Meeting, Brussels, May 30th-June 1st 2007*. Newcastle upon Tyne: Cambridge Scholars Publishing, pp. 539-562
- Brickley, M., 2004. "Compiling a Skeletal Inventory: Articulated Inhumed Bone" in Brickley, M., McKinley, J. (eds.) *Guidelines to the Standards for Recording Human Remains*. Southampton: BABAO, pp. 6-7
- Brickley, M., McKinley, J., 2004. *Guidelines to the Standards for Recording Human Remains*. Southampton: BABAO
- British Geological Survey, 2004. Oxygen Isotope Values for Modern European Drinking Water. Nottingham: NERC
- British Geological Survey, 2022a. British Isotope Domains (Great Britain). [Online] Available at: <https://www.bgs.ac.uk/datasets/biosphere-isotope-domains-gb/> [Accessed Dated: 5th January 2022]
- British Geological Survey 2022b. Geology of Britain Viewer (Classic). [Online] Available at: [Geology of Britain viewer | British Geological Survey \(BGS\)](#) [Accessed Dated 15th February 2022]
- Brooks, S., Suchey, J., 1990. Skeletal Age Determination Based on the Os Pubis: A Comparison of the Acsadi-Nemeskeri and Suchey-Brooks Methods. *Human Evolution*, 5(1), pp. 227-238
- Brothwell, D., 1981. *Digging up Bones: The Excavation, Treatment, and Study of Human Skeletal Remains*. 3rd Edition. New York: Cornell University Press
- Brown, T., Nelson, D., Vogel, J., Southon, J., 1988. Improved Collagen Extraction by Modified Longin Method. *Radiocarbon*, 30(1), 171-177

- Budd, P., Montgomery, J., Evans, J., Barreiro, B., 2000. Human Tooth Enamel as a Record of the Comparative Lead Exposure of Prehistoric and Modern People. *Science of the Total Environment*, 263(1-3), pp. 1-10
- Buikstra, J.E., Ubelaker, D.H., 1994. Standards for Data Collection from Human Remains. Fayetteville: Arkansas Archaeological Survey
- Capo, R., Stewart, B., Chadwick, O., 1998. Strontium Isotopes as Tracers of Ecosystem Processes: Theory and Methods. *Geoderma*, 82(1-3), pp. 197-225
- Carlton, R., 2018. A Bronze Age Cist at Oakslaw near Rock, Northumberland. [Report] Durham: Archaeological Practice Ltd
- Chenery, C., Pashley, V., Lamb, A., Sloane, H., Evans, J., 2012. The Oxygen Isotope Relationship Between the Phosphate and Structural Carbonate Fractions of Human Bioapatite. *Rapid Communications in Mass Spectrometry*, 26(1), 309-319
- Chinique de Armas, Y., Mavridou, A., Dominguez, J., Hanson, K., Laffoon, J., 2022. Tracking Breastfeeding and Weaning Practices in Ancient Populations by Combining Carbon, Nitrogen and Oxygen Stable Isotopes from Multiple Non-Adult Tissues. *PLoS ONE*, 17(2), pp. 1-28
- Connell, B., 2004. "Compiling a Dental Inventory" in Brickley, M., and McKinley, J. (eds.) *Guidelines to the Standards for Recording Human Remains*. Southampton: BABAO, 8-9
- Coplen, T., 1988. Normalisation of Oxygen and Hydrogen Isotope Data. *Chemical Geology: Isotope Geoscience Section*, 72(4), 293-297
- Cox, M., 2000. "Ageing Adults From the Skeleton", in Cox, M., Mays, S. (eds.) *Human Osteology in Archaeology and Forensic Science*. London: Greenwich Medical Media, 61-81
- Crowder, K., Montgomery, J., Grocke, D., Filipek, K., 2019. Childhood "Stress" and Stable Isotope Life-Histories in Transylvania. *International Journal of Osteoarchaeology*, 29(4), pp. 644-653
- Dansgaard, W., 1964. Stable Isotopes in Precipitation. *Tellus*, 16(4), pp. 436-468
- Darling, W., Talbot, J., 2003. The O and H Stable Isotope Composition of Freshwaters in the British Isles 1: Rainfall. *Hydrology and Earth System Sciences*, 7(1), pp. 161-181

- Darling, W., Bath, A., Talbot, J., 2003. The O and H Stable Isotope Composition of Freshwaters in the British Isles 2: Surface Waters and Groundwater. *Hydrology and Earth System Sciences*, 7(1), 183-195
- Daux, V., Lécuyer, C., Hérin, M., Amiot, R., Simon, L., Fourel, F., Martineau, F., Lynnerup, N., Reyhler, H., Escarguel, G., 2008. Oxygen Isotope Fractionation Between Human Phosphate and Water Revisited. *J. Hum. Evol.*, 55(1), 1138
- DeNiro, M., Epstein, S., 1978. Influence of Diet on the Distribution of Carbon Isotopes in Animals. *Geochimica et cosmochimica acta*, 42(5), pp. 495-506
- DeNiro, M.J., 1985. Postmortem Preservation and Alteration of in Vivo Bone Collagen Isotope Ratios in Relation to Palaeodietary Reconstruction. *Nature*, 317(6040), pp. 806
- Dyer, J., 2002. Ancient Britain. London: Routledge
- Drasch, G., 1982. Lead Burden in Prehistorical, Historical, and Modern Human Bones. *Sci Total Environ.*, 24(3), pp. 199-231
- Ericson, J.E., 1985. Strontium Isotope Characterisation in the Study of Prehistoric Human Ecology. *Journal of Human Evolution*, 14(1), pp. 503-514
- Evans, J., Montgomery, J., Wildman, G., Boulton, N., 2010. Spatial Variations in Biosphere $^{87}\text{Sr}/^{86}\text{Sr}$ in Britain. *Journal of the Geological Society*, 167(1), pp. 1-4
- Evans, J., Chenery, C., Montgomery, J., 2012. A Summary of Strontium and Oxygen Isotope Variation in Archaeological Human Tooth Enamel Excavated from Britain. *J. Anal. AT. Spectrom.*, 27(1), pp. 754-764
- Evans, J., Mee, K., Chenery, C., Cartwright, C., Lee, K., Marchant, A., 2018. User Guide for the Biosphere Isotope Domains GB (Version 1) Dataset and Web Portal. *British Geological Survey Open Report*, OR/18/005, pp. 1-14
- Font, L., Davidson, J., Person, D., Nowell, G., Jerram, D., Ottley, C., 2008. Sr and Pb Isotope Micro-Analysis of Plagioclase Crystals from Skye Lavas: An Insight into Open-System Processes in a Flood Basalt Province. *Journal of Petrology*, 49(8), 1449-1471
- Fowler, C., 2013. The Emergent Past: A Relational Realist Archaeology of Early Bronze Age Mortuary Practices. Oxford: OUP Oxford

- Fowler, C., Wilkin, N., 2016. "Early Bronze Age Mortuary Practices in North-East England and South-East Scotland: Using Relational Typologies to Trace Social Networks" in Crellin, R., Fowler, C., Tipping R. (eds.) *Prehistory Without Borders: The Prehistoric Archaeology of the Tyne-Forth Region*. Oxford: Oxbow Books, pp. 112-135
- Friend, A., 2012. What Does the Archaeological Evidence of the Mary Rose Reveal about the Archer and Practice of Archery, and how will the Mary Rose Trust Interpret this Evidence for its Visitors in the New Museum [Dissertation]. Bangor: Bangor University
- Groves, S.E., Roberts, C.A., Lucy, S., Pearson, G., Grocke, D.R., Nowell, G., Macpherson, C.G., Young, G., 2013. Mobility Histories of the 7th-9th Century AD People Buried at Early Medieval Bamburgh, Northumberland, England. *American Journal of Physical Anthropology*, 151(1), pp. 462-476
- Google Earth Pro, 2018. *Rock, Alnwick 55°28'44.46"N 1°39'35.82"W, elevation 75m* [accessed 17th March 2021]
- Graustein, W.C., 1989. "⁸⁷Sr/⁸⁶Sr Ratios Measure the Sources and Flow of Strontium in Terrestrial Ecosystems" in Rundel, P.W., Ehleringer, J.R., Nagy, K.A. (eds.) *Stable Isotopes in Ecological Research*. New York: Springer, pp. 491-512
- Haavikko, K., 1970. The Formation and the Alveolar and Clinical Eruption of the Permanent Teeth: An Ortho-panto-graphoc study. *Proceedings of the Finnish Dental Society*, 66(1), pp. 101-170
- Hillson, S., 1996. *Dental Anthropology*. Cambridge: Cambridge University Press, pp. 373
- Holst, M., 2010. *Osteological Analysis: Coppergate York*. York: York Archaeological Trust
- Hunt, D.R., Bullen, L., 2007. The Frequency of Os Acromial in the Robert J. Terry Collection. *International Journal of Osteoarchaeology*, 17(3), pp. 309-317
- Jay, M., Richards, M., 2019. "Carbon and Nitrogen Isotopic Analysis" in Parker Pearson, M., Sheridan, A., Jay, M., Chamberlain, A., Richards, M., Evans, J. (eds.) *The Beaker People: Isotopes, Mobility and Diet in Prehistoric Britain*. Oxford: Oxbow Books, pp. 369-406
- Jit, I., Kulkarni, M., 1976. Times of Appearance and Fusion of Epiphysis at the Medial End of the Clavicle. *Indian J Med Res.*, 64(5), pp. 773-82

- Kibblewhite, M., Toth, G., Hermann, T., 2015. Predicting the Preservation of Cultural Artefacts and Buried Materials in Soil. *Science of the Total Environment*, 529(1), 249-263
- Lightfoot, E., O'Connell, T., 2016. On the Use of Biomineral Oxygen Isotope Data to Identify Human Migrants in the Archaeological Record: Intra-Sample Variation, Statistical Methods and Geographical Considerations. *PLos ONE*, 11(4), pp. 1-29
- Loftus, E., Sealy, J., 2012. Technical Note: Interpreting Stable Carbon Isotopes in Human Tooth Enamel: An Examination of Tissue Spacings from South Africa. *AM J Phys Anthropol.*, 147(2), pp. 499-507
- Lovejoy, C.O., Meindl, R., Pryzbeck, T., Mensforth, R., 1985. Chronological Metamorphosis of the Auricular Surface of the Ilium: A New Method for the Determination of Adult Skeletal Age at Death
- Manea-Kritchen, M., Patterson, C., Miller, G., Settle, D., Erel, Y., 1991. Comparative Increases of Lead and Barium with Age in Human Tooth Enamel, Rib and Ulna. *Sci. Total Environ.*, 107(1), pp.179-203
- Mays, S., 2010. The Archaeology of Human Bones. 2nd edition. London: Routledge
- Mays, 2016. Estimation of Stature in Archaeological Human Skeletal Remains from Britain. *American Journal of Physical Anthropology*, 161(4), pp. 646-655
- Mays, S., Elders, J., Humphrey, L., White, W., Marshal, P., 2013. Science and the Dead: A Guideline for the Destructive Sampling of Archaeological Human Remains for Scientific Analysis. London: Advisory Panel on the Archaeology of Burials in England
- McArthur, J., Howarth, R., Bailey, T., 2001. Strontium Isotope Stratigraphy: LOWESS Version 3: Best Fit to the Marine Sr-isotope Curve for 0-509 MA and Accompanying Look-up Table for Deriving Numerical Age. *The Journal of Geology*, 109(2), pp. 155-170
- McKinley, 2004. "Compiling a Skeletal Inventory: Disarticulated and Co-Mingled Remains", in Brickley, M., McKinley, J. (eds.) *Guidelines to the Standards for Recording Human Remains*. Southampton: BABAO, 9-13
- Montgomery, J., Evans, J., Powlesland, D., Roberts, C., 2005. Continuity or Colonisation in Anglo-Saxon England? Isotope Evidence for Mobility, Subsistence Practice, and Status at West Heslerton. *American Journal of Biological Anthropology*, 126(2), pp. 123-138

Montgomery, J., Evans, J., Cooper, R., 2007. Resolving Archaeological Populations with Sr-Isotope Mixing Models. *Applied Geochemistry*, 22(7), pp. 1502-1514

Montgomery, J., 2010. Passports from the Past: Investigating Human Dispersals Using Strontium Isotope Analysis of Tooth Enamel. *Annals of Human Biology*, 27(3), pp. 325-346

Montgomery, J., Evans, J., Chenery, S., Pashley, V., Kilgrove, K., 2010. "Gleaming White and Deadly": Using Lead to Track Human Exposure and Geographic Origins in the Roman Period in Britain. *Journal of Roman archaeology; supplementary series*, Suppl. 78(1), pp. 199-226

Montgomery, J., Gledhill, A., 2013. "Diet and Origin: The Isotope Evidence" in Melton, D., Montgomery, J., Knusel, C. (eds.) *Gristhorpe Man: A Life and Death in the Bronze Age*. Oxford: Oxbow Books, pp. 129-141

Montgomery, J., Jay, M., 2013. "The Contribution of Skeletal Isotope Analysis to Understanding the Bronze Age in Europe" in Fokkens, H., Harding, A. (eds.) *The Oxford Handbook of the European Bronze Age*. Oxford: Oxford University Press, pp. 179-196

Montgomery, J., Grimes, V., Buckberry, J., Evans, J., Richards, M., Barrett, J., 2014. Finding Vikings with Isotope Analysis: The View from Wet and Windy Islands. *Journal of the North Atlantic*, Special Volume 7, pp. 54-70

Montgomery, J., Evans, J., Towers, J., 2019a. "Strontium Isotopic Analysis" in Parker Pearson, M., Sheridan, A., Jay, M., Chamberlain, A., Richards, M., Evans, J. (eds.) *The Beaker People: Isotopes, Mobility and Diet in Prehistoric Britain*. Oxford: Oxbow Books, pp. 369-406

Montgomery, J., Towers, J., Evans, J., Pellegrini, M., Jay, M., Richards, M., 2019b. "Appendix 10: Results of Strontium and Oxygen Isotope Analysis" in Parker Pearson, M., Sheridan, A., Jay, M., Chamberlain, A., Richards, M., Evans, J. (eds.) *The Beaker People: Isotopes, Mobility and Diet in Prehistoric Britain*. [Online] Available at: <https://doi.org/10.6084/m9.figshare.7532669> [Accessed Dated 20th January 2022]

Moorees, C., Fanning, E., Hunt, E., 1963. Age Variation of Formation Stages for Ten Permanent Teeth. *Journal of Dental Research*, 42(1), 1490-1502

O'Connell, T., Hedges, R., 1999. Isotopic Comparison of Hair and Bone: Archaeological Analyses. *Journal of Archaeological Science*, 26(1), 661-665

Ogden, A., 2008. "Advances in the palaeopathology of teeth and jaws". In: Pinhasi, R., & Ma y s, S. (Eds.), *Advances in Human Palaeopathology*. Hoboken: John Wiley & Sons, pp. 283-307

Parker Pearson, M., Chamberlain, A., Jay, M., Richards, M., Sheridan, A., Curtis, N., Evans, J., Gibson, A., Hutchison, M., Mahoney, P., Marshall, P., Montgomery, J., Needham, S., O'Mahoney, S., Pellegrini, M., Wilkin, N., 2016. Beaker People in Britain: Migration, Mobility and Diet. *Antiquity*, 90(1), 620-637

Parker Pearson, M., Sheridan, A., Jay, M., Chamberlain, A., Richards, P., Evans, J., Chiu, L., Curtis, N., Deter, C., Gibson, A., Hutchison, M., Johns, S., Mahooney, P., Marshall, P., Montgomery, J., Needham, S., Nechlich, O., Nystrom, P., Pellegrini, M., Schmidt, C., Thomas, S., Towers, J., Wilkin, N., 2019. The Beaker People: Isotopes, Mobility and Diet in Prehistoric Britain. Oxford: Oxbow Books

Parker Pearson, M., Jay, M., Sheridan, A., 2019a. "Introduction" in Parker Pearson, M., Sheridan, A., Jay, M., Chamberlain, A., Richards, M., Evans, J. (eds.) *The Beaker People: Isotopes, Mobility and Diet in Prehistoric Britain*. Oxford: Oxbow Books, pp. 1-42

Parker Pearson, M., Jay, M., Montgomery, J., Sheridan, A., Needham, S., 2019b. "Synthesis, Discussion and Conclusions" in Parker Pearson, M., Sheridan, A., Jay, M., Chamberlain, A., Richards, M., Evans, J. (eds.) *The Beaker People: Isotopes, Mobility and Diet in Prehistoric Britain*. Oxford: Oxbow Books, pp. 425-460

Pellegrini, M., Jay, M., Richards, M., 2019. "Oxygen Isotopic Analysis" in Parker Pearson, M., Sheridan, A., Jay, M., Chamberlain, A., Richards, M., Evans, J. (eds.) *The Beaker People: Isotopes, Mobility and Diet in Prehistoric Britain*. Oxford: Oxbow Books, pp. 407-424

Price, T.D., Burton, J.H., Bentley, R.A, 2002. The Characterisation of Biologically Available Strontium Isotope Ratios for the Study of Prehistoric Migration. *Archaeometry*, 44(1), pp. 117-135

Price, T.D., Grupe, G., Schroter, P., 1994. Reconstruction of Migration Patterns in the Bell Beaker Period by Stable Strontium Isotope Analysis. *Applies Geochemistry*, 9(1), pp. 413-417

- Redfern, R., Hamlin, C., Athfield, N.B., 2010. Temporal Changes in Diet: A Stable Isotope Analysis of Late Iron Age and Roman Dorset, Britain. *Journal of Archaeological Science*, 37(1), pp. 1149-1160
- Richards, M., 2020. "Isotope Analysis for Diet Studies" in Richards, M., Britton, K. (eds.) *Archaeological Science: An Introduction*. Cambridge: Cambridge University Press, pp. 125-143
- Roberts, C., Connell, B., 2004. "Guidance on Recording Palaeopathology" in Brickley, M., and McKinley, J. (eds.) *Guidelines to the Standards for Recording Human Remains*. Southampton: BABAO, pp. 34-39
- Roberts, C., Manchester, K., 2010. *The Archaeology of Disease*. Third Edition. Stroud: The History Press
- Schaefer, M., 2008. A Summary of Epiphyseal Union Timings in Bosnian Males. *International Journal of Osteoarchaeology*, 18(5), pp. 536-545
- Schaefer, M., Black, S., Scheuer, L., 2009. *Juvenile Osteology: A Laboratory and Field Manual*. London: Elsevier Academic Press
- Schoeninger, M., DeNiro, M., 1984. Nitrogen and Carbon Isotopic Composition of Bone Collagen from Marine and Terrestrial Animals. *Geochimica et Cosmochimica acta*, 48(4), pp. 625-639
- Schwartz, J.H., 1995. *Skeleton Keys: An Introduction to Human Skeletal Morphology, Development and Analysis*. Oxford: Oxford University Press
- Sealy, J.C., Armstrong, R., Schrire, C., 1995. Beyond Lifetime Averages: Tracing Life Histories through Isotopic Analysis of Different Calcified Tissues from Archaeological Skeletons. *Antiquity*, 69(1), pp. 290-300
- Simpson, R., Cooper, D., Swanston, T., Coulthard, I., Varney, T., 2021. Historical Overview and New Directions in Bioarchaeological Trace Element Analysis: A Review. *Archaeological and Anthropological Sciences*, 13(24), pp. 1-27
- Smith, 1984. Patterns of Molar Wear in Hunter-Gatherers and Agriculturalists. *American Journal of Physical Anthropology*, 63(1), pp. 39-56

- Stewart, N., Gerlach, R., Gowland, R., Gron, K., Montgomery, J., 2017. Sex Determination of Human Remains from Peptides in Tooth Enamel. *PNAS*, 114(52), pp. 13649-13654
- Stirland, A., 1992. Comparisons of the Scapula in Young Adult Medieval males: An Application of Hrdlicka. *Anthropologie*, 30(1)
- SUERC 102217 (GU59765). Radiocarbon Dating Certificate 01 February 2022. Glasgow: University of Glasgow
- SUERC 102214 (GU59697). Radiocarbon Dating Certificate 09 February 2022. Glasgow: University of Glasgow
- Towers, J., 2013. An Isotopic Investigation into Calving Seasonality, Diet, and Dairying in British Prehistoric Cattle [PhD Thesis]. Bradford: University of Bradford
- Towers, J., Gledhill, A., Bond, A., Montgomery, J., 2014. An Investigation of Cattle Birth Seasonality Using $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ Profiles Within First Molar Enamel. *Archaeometry*, 56(S1), pp. 208-236
- Trotter, M., 1970. 'Estimation of Stature from Intact Long Bones' in Stewart, T.D. (eds.) *Personal Identification in Mass Disasters*. Washington: Smithsonian Institution Press, 71-83
- Ubelaker, D.H., 1979. *Human Skeletal Remains: Excavation, Analysis, and Interpretation*. Washington, DC: Smithsonian Institution Press
- Van Klinken, G.J., 1999. Bone Collagen Quality Indicators for Palaeodietary and Radiocarbon Measurements. *Journal of Archaeological Science*, 26(6), pp. 687-695
- Waddington, C., Bailey, G., Boomer, I., Milner, N., 2005. A Bronze Age Cist Cemetery at Howick, Northumberland. *Archaeological Journal*, 162(1), 65-95
- White, T.D., Folkens, P.A., 2005. *The Human Bone Manual*. Burlington, San Diego and London: Elsevier Academic Press
- White, T., Black, M., Folkens, P., 2011. *Human Osteology*. Third Edition. London: Elsevier Academic Press

Appendices

Appendix I: Stable Isotope Analysis Background

As stable isotope analysis of humans remains has been used as a scientific method within this study to explore the life history of the Oakslaw individual, it is necessary to note the basic principles underpinning the use of strontium, oxygen, carbon, and nitrogen isotope ratios to infer mobility and diet. Starting with strontium isotope analysis, this stable isotope has been used to provenance the geographical origins of individuals for over three decades, with early publications (see for example: Ericson 1985; Sealy *et al.* 1995; Price *et al.* 1994) highlighting the value of this direct method of analysis as an additional or alternative source of evidence with which to interpret mobility in comparison to the past reliance on indirect evidence such as burial tradition and material culture change (Montgomery 2010). Biosphere strontium isotope ratios reflect the underlying geology of the local area, and can vary significantly depending on the age of the bedrock from which they are derived as geologically older rocks are expected to produce higher $^{87}\text{Sr}/^{86}\text{Sr}$ values than younger lithologies (Price *et al.* 2002). From these rocks, strontium is released into surrounding soils and groundwater sources and can then enter the food chain into plants, animals, and humans, whose $^{87}\text{Sr}/^{86}\text{Sr}$ values will therefore reflect the local geology (Graustein 1989), particularly because strontium isotope ratios do not undergo fractionation during biological processes (Blum *et al.* 2000). Importantly, strontium isotope ratios measured in enamel and bone represent an average $^{87}\text{Sr}/^{86}\text{Sr}$ value of all the food and drink consumed and incorporated into the mineral component of these tissues during their formation (Montgomery 2010), therefore meaning that if an individual had a diet procured from the local region, their measured strontium isotope ratios will be consistent with the local geological signature (Price *et al.* 2002). This principle allows locality and mobility to be interpreted, as if a person's measured $^{87}\text{Sr}/^{86}\text{Sr}$ value is inconsistent with those expected for the local biosphere and underlying geology of their burial place, it can be suggested that the person did not source their diet locally and may themselves be non-local to the area (Bentley 2006). Typically, enamel $^{87}\text{Sr}/^{86}\text{Sr}$ values are used to interpret childhood residential origins as this tissue does not remodel once it has completed formation during the early years of life (Hillson 1996), and can be compared to the $^{87}\text{Sr}/^{86}\text{Sr}$ values of remodelling bone or later-forming enamel to infer mobility and migration during an individual's lifetime (Price *et al.* 2002). However, inferring mobility is not always a simple task and there are many caveats to consider when investigating potential evidence

for mobility and migration. For instance, strontium isotope analysis can only identify first generation migrants unlike aDNA analysis, (Montgomery 2010), and most importantly can only be used with confidence to rule out possible origins, which can make pinpointing the most likely origin difficult due to many areas of Britain and Europe sharing similar geologies and thus producing similar strontium isotope ratios (Montgomery *et al.* 2014). Similarly, these shared $^{87}\text{Sr}/^{86}\text{Sr}$ values across different regions cause perhaps the most restrictive limitation of strontium isotope analysis, which is that individuals who move between areas of similar geologies cannot be identified as migrants isotopically, thus often resulting in an underestimation of total migrant numbers within studied populations (Parker Pearson *et al.* 2016; 2019b).

Oxygen isotope ratios can also be measured in enamel hydroxyapatite and used alongside strontium isotopes within mobility studies. Instead of being derived from geological sources, $\delta^{18}\text{O}$ values in human tissue such as enamel reflect the oxygen isotope ratio composition of drinking water ingested during tissue formation, which in turn is derived from local precipitation levels (Darling *et al.* 2003). Differences observed between the measured $\delta^{18}\text{O}$ values in enamel and those expected for an individual's place of burial can support a potential non-local origin, like with strontium, and are often useful within British samples to discriminate between a likely origin on the east or west side of the country, as the higher rainfall along the west coast can generate higher $\delta^{18}\text{O}$ values in local individuals compared to those originating from further east (Evans *et al.* 2018). Oxygen isotope ratios are often more variable than strontium ratios however, as temperature, altitude, rainfall levels, and latitude can impact the local precipitation values (Darling and Talbot 2003), and the values measured in enamel must be calibrated as oxygen undergoes fractionation in the body after ingestion (Chenery *et al.* 2012). The limitations of oxygen isotope analysis are similar to those for strontium isotope analysis as the same $\delta^{18}\text{O}$ values can be generated from geographically distant areas (Darling *et al.* 2003), with the added caveat that the necessary calibrations performed on the oxygen isotope ratios to compare them with modern drinking water values (see for example: Daux *et al.* 2008; Chenery *et al.* 2012) can yield very high analytical uncertainties of up to $\pm 3.5\text{‰}$ (Pollard *et al.* 2011), thus restricting the confidence with which interpretations of mobility can be made. Additionally, although oxygen isotope ratios measured in human samples can vary significantly, this is not always related to movement and mobility, as it has been shown that the $\delta^{18}\text{O}$ values of ingested water can be modified and increased by culturally-mediated behaviours and activities such as boiling,

brewing and stewing to such a degree that they may not reflect the local precipitation (Lightfoot and O'Connell 2016). Furthermore, enamel $\delta^{18}\text{O}$ values from early forming teeth must be treated with extra caution, as if the individual was being breastfed during the enamel's formation, the measured $\delta^{18}\text{O}$ values will not be reflective of the local precipitation and will instead likely be higher than expected as breastmilk is usually enriched in $\delta^{18}\text{O}$ compared to drinking water sources (Chinique de Armas *et al.* 2022).

Carbon and nitrogen isotopes on the other hand are often used in combination to reconstruct the diets of archaeological individuals, with their analysis now a well-established direct scientific method of inferring dietary behaviours, profiles, and even change (see for example: Montgomery and Gledhill 2013; Beaumont *et al.* 2013). $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values measured in bone and dentine collagen are incorporated into these tissues from the diet, and dietary protein sources in particular, and undergo increasing fractionation from the dietary source at each trophic level shift, with herbivores expected to have more negative $\delta^{13}\text{C}$ values and lower $\delta^{15}\text{N}$ values than omnivores and carnivores (Jay and Richards 2019). If herbivore isotopic data is available, carbon and nitrogen isotope ratios from human collagen samples can be compared to this data to investigate whether the difference between them is indicative a trophic level shift, which is generally accepted to be represented by a 3-5‰ increase in $\delta^{15}\text{N}$ values and a 0-2‰ increase in $\delta^{13}\text{C}$ values (Bocherens and Drucker 2003). Moreover, carbon isotope ratios can help distinguish between the consumption of plants using the C_3 or C_4 photosynthetic pathways, with C_3 plants commonly found in temperate environments expected to have lower $\delta^{13}\text{C}$ values than C_4 plants from more arid environments such as millet and maize (Richards 2020), which is then reflected in human collagen $\delta^{13}\text{C}$ values (DeNiro and Epstein 1978). For prehistoric populations in particular, these isotope ratios are most commonly used to distinguish between terrestrial and marine resource consumption, as well as identifying trophic levels (Jay and Richards 2019). Terrestrial diets typically yield lower $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values in collagen samples than diets with a significant marine resource contribution, which are instead expected to show particularly increased $\delta^{15}\text{N}$ values indicative of a significant trophic level shift due to the longer and more complex food chains within marine environments (Schoeninger and DeNiro 1984). The development of analysing carbon and nitrogen isotope ratios within incremental dentine collagen profiles has also enabled short-term dietary changes and periods of nutritional or physiological stress to be inferred and assigned approximate ages and time frames, by interpreting changes in the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values across a defined chronological period of tooth formation (Beaumont *et al.* 2013; 2014;

2015; Beaumont and Montgomery 2015; 2016). Therefore, whilst carbon and nitrogen isotope analysis is limited in its ability to infer detailed information about ancient diets without comparative data, the ability to distinguish between marine and terrestrial food sources, plant and animal consumption, as well as C₃ and C₄ plants is generally more than adequate to reconstruct a general diet for an individual or even a population (Richards 2020), with the increasing use and development of high-resolution incremental dentine profiling improving the identification of short-term dietary changes (Beaumont *et al.* 2013; 2014; Beaumont and Montgomery 2015).

Appendix II: Skeletal Recording Form

SKELETAL RECORDING FORM			
Site Name: Oakslaw, Rock		Skeleton no.: 1	
Burial	Period:	Early Bronze Age	
	Position:	Flexed (lying on right side)	
	Orientation:	East-West (head to west facing south)	
	Position of Hands:	Bent at elbows across chest	
	Anomalies:	Fibrous material covering skeleton	
	Intercutting Features:	N/A	
	Position in Cemetery:	N/A	
	Associated Skeletons:	N/A	
	Associated Burials:	N/A	
Finds	Artefacts in Grave:	Beaker Vessel	
	Artefacts with Skeleton:	N/A	
	Animal Bone in Grave:	Possible unidentified thin, long bone (too eroded)	
	Animal Bone with Skeleton:	N/A	
	Additional Human Bone:	N/A	
Fragmentation:	Moderate	Surface Preservation:	Grade 4-5
Completeness:	60-75%	Stature:	164.46cm (± 3.27 cm)
Age:	18-25	Sex:	M?
Pathology:	Possible os acromiale; dental calculus (84% prevalence); periodontal disease (lower left mandible)		

Inventory							
Bone	Complete	Proximal Epiphysis	Proximal/Medial	Central	Distal/lateral	Distal Epiphysis	Fragments
Clavicle R	No	✓	✓	✓	✓	✗	1
Clavicle L	-	-	-	-	-	-	0
Humerus R	Yes	✓	✓	✓	✓	✓	1
Humerus L	No	✓	✓	✓	✓	✗	1
Radius R	No	✗	✓	✓	✓	✓	1
Radius L	No	✗	✗	½	✓	✓	1 (+1 unsided radius head)
Ulna R	No	✓	✓	½	✗	✗	1
Ulna L	No	✗	✗	✗	✓	✓	1
Femur R	Yes	✓	✓	✓	✓	✓	1
Femur L	No	✗	✓	✓	✓	✓	1
Tibia R	Yes	✓	✓	✓	✓	✓	1
Tibia L	Yes	✓	✓	✓	✓	✓	1
Fibula R	No	✗	✗	½	✓	✓	1
Fibula L	No	✗	✓	✓	✓	✗	1

Bone	Complete	Acromion / Pubis	Coracoid / Ischium	Blade / Ilium	Fragments
Scapula R	N	✗	✗	✓	1 (intact blade and spine)
Scapula L	N	✗	✗	glenoid fossa and lateral border	1
Pelvis R	N	-	-	-	1 fragment of unsided ilium
Pelvis L	N	-	-	-	

Bone	Part	1	2	3	4	5	1	2	3	4	5	Count
Metacarpal	Proximal	✓	✓	½	✗	✗	✓	✓	✓	✗	✗	8
	Distal	✓	✓	✓	✗	✓	✓	✓	✓	✓	✗	
Proximal Phalanx	Proximal	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	10
	Distal	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Int. Phalanx	Proximal	-	✓	✗	✗	✓	-	✗	✓	✓	✗	4
	Distal	-	✓	✗	✗	✓	-	✗	✓	✓	✗	
Distal Phalanx	Proximal	✓	✓	✗	✗	✗	✗	✗	✓	✓	✗	4
Metatarsal	Proximal	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	10
	Distal	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	

Proximal Phalanx	Proximal	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	9
	Distal	✓	✗	✗	✗	✓	✓	✓	✓	✓	✗	✗	
Int. Phalanx	Proximal	-						-					0
	Distal	-						-					
Distal Phalanx	Proximal												0

Capitate		Hamate		Lunate		Pisiform		Scaphoid		Trapezoid		Trapezium		Triquetral	
R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L
✗	✓	✗	✗	✗	✓	✗	✗	✓	✓	✓	1/2	✓	1/2	✗	✓

Patella		Calcaneus		Talus		Cuboid		Navicular		M Cuneiform		I Cuneiform		L Cuneiform	
R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L
✓	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Frontal		Parietal		Occipital		Temporal		Zygomatic		Sphenoid		Mandible		Maxilla	
R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L
✓	✓	✓	1/2	✓	✓	✓	1/2	✓	✓	✓	✓	✓	✓	✓	✓
No. of Skull Fragments: 4 (+20-25 small)															

Manubrium		Sternum		Xiphoid		Hyoid		Thyroid		Ossicles		F Sesamoids		H Sesamoids	
R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L
✓	✓	✗	✗	✗	✗	1 greater horn		✗	✗	✗	✗	✗	✗	✗	✗

Comments:

- Areas covered by fibre (L cranium and mandible; L femur; R tibia)
- Cortex lost and/or peeling in places
- Preservation – sandstone-like texture (skull); variable preservation (right shoulder)
- Several hundreds of small unidentifiable fragments
- Ribs originally missing – found after analysis

Teeth: 32 present + 32 tooth positions/sockets present

Key: P – tooth present

R	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	L
	8	7	6	5	4	3	2	1	1	2	3	4	5	6	7	8	
	8	7	6	5	4	3	2	1	1	2	3	4	5	6	7	8	
	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	

Vertebrae

Cervical	• C1 – not preserved • C2 – centre preserved • C3-C7 – min 4. Bodies + R arch
Thoracic	• 1 R arch (C7/T1/T2?) • Min. 6 arches
Lumbar	-
Sacral	-
Coccyx	-

Ribs

Bone	Head		Central		Sternal	
	R	L	R	L	R	L
1	✓		✓		✓	
2	✓		✓		x	
3	✓		✓		x	
4	✓		✓		x	
5	✓		✓		x	
6	x		✓		x	
7	x		✓		x	
8	x		✓		x	
9						
10						
11						
12						
Fragments	8 ribs (right) – all duplicating (1 fragment each) Min. 7 rib shaft fragments (unsided)					

Sex Determination		
Skeletal Characteristics (Observable)		
Anterior Mandible	M?	
Supra-Mastoid Crest	F? (PM damage)	
Nuchal Crest	F?	
Supra-Orbital Ridge	M? / I	
Orbital Rims	M	
Forehead Slope	M?	
Frontal Bossing	M	
Parietal Bossing	F? (PM damage)	
Measurements (Observable)		
Bone	R (mm)	L (mm)
Scapula Glenoid Width (F: 26mm, M: 29mm)	25.15 (F)	-
Humeral Head Width (F: 43mm, M: 47mm)	42.15 (F)	41.47 (F)
Femoral Distal Epiphysis Width (F: 74mm, M: 76mm)	71.80 (F)	-
Sex: • Cranium – overall more male features (some female traits) • Observation inhibited by fibrous material • Pelvis lost post-mortem • All metrics fall in female range (possible small male?) Estimation = M? (mixed expression of traits)		

Post-Cranial Measurements		
Bone	R (mm)	L (mm)
Scapula Glenoid Width	33.62	
Humerus Length	342	
Humerus Midshaft Width	19.50	
Humerus Distal Epiphysis Width	56	
Femoral Shaft Length	433	
Femoral Shaft Length Diagonal	428	
Femoral AP Diaphysis Width	25.6	
Femoral ML Diaphysis Width	30.81	
Tibia Shaft Length		373
Tibia AP Diaphysis Width		27.61
Tibia ML Diaphysis Width		20.76

Age Determination			
Young Adult			
Fusion/Development (observable)	Stage	Age	Comments
Dental Development	All 4 third molars erupted	18+	
Clavicle Fusion	Small flake	18 – 25	
Acromion Fusion	Not fused	18 – 20?	Possible os acromiale
Vertebral Epiphyses Fusion	Possible annular ring on cervical vertebra	17 – 25?	Preservation issues
Proximal Humerus Fusion	Fused		
Humeral Medial Epicondyle Fusion	Fused		
Distal Radius Fusion	Fused		
Femoral Head Fusion	Fused		
Distal Femur Fusion	Fused		
Proximal Tibia Fusion	Fused		
Femoral Greater Trochanter Fusion	Fused		
Distal Tibia Fusion	Fused		
Distal Fibula Fusion	Fused		
Adult			
Dental Wear (Brothwell)	1	17 – 25	
Skeletal Fusion	Clavicle fusing	18 - 25	
Age: • Fusion – suggests 18-25 (clavicle only partially fused) • Dentition – suggests 18+ • Dental wear – suggests young adult (17-25)			

Dentition – Calculus and Wear																
Key:																
• - (no calculus) • F (flecks of calculus) • S (slight severity) • N/A (tooth unobservable) • Positions: o (occlusal); d (distal); l (lingual); m (mesial); b (buccal)																
	Right								Left							
Tooth (Maxilla)	8	7	6	5	4	3	2	1	1	2	3	4	5	6	7	8
Calculus	-	-	S	-	F	F	F	F	F	F	F	N/A	N/A	N/A	N/A	N/A
Position	-	-	l	-	l	m	b	b	m	m	M					

Wear	1		3	2	2	3	2	4	3	2	2	2	2	3	2	1
Wear	1	1/2	3	2	2	3	3	3	3	2	2	2	2	3	1/2	1
Position	I/d	I/m	I	I	I	I	I	I/b	I/m	I/m/b	I/b	I/m/b	I	I	I	I
Calculus	S	S	S	S	F	F	S	S	S	S	S	S	S	S	S	S
Tooth (Mandible)	8	7	6	5	4	3	2	1	1	2	3	4	5	6	7	8
	Right								Left							

Pathology Description

- No observed spinal joint disease
- No observed degenerative joint disease
- R scapula – tip of acromion process absent
 - Surviving portion = linear edge at right angles (porous surface)
 - Magnification = traces of original bone surface present
 - Possible os acromiale (damage inhibits confidence of diagnosis)
 - However – extensive post-mortem damage also observed here
 - L scapula absent (no comparison)